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Merging Science and Management in a Rapidly Changing World:

Biodiversity and Management of the Madrean Archipelago III

May 1–5, 2012
Tucson, Arizona

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Abstract

The Madrean Archipelago or Sky Islands region of the southwestern United States and northern Mexico is recognized for its unique biological diversity, natural beauty, and cultural heritage. This 2012 conference brought together scientists, managers, students, and other interested parties from the United States and Mexico to share their knowledge and passion about the region and to identify needs and creative solutions for existing and emerging problems. More than 300 people attended the conference including a large and energetic contingent from northern Mexico. The conference provided a forum to update the state-of-knowledge that has evolved since the first conference in 1994 and the second conference in 2004. It also provided a setting for the formation of new friendships and partnerships. These proceedings contain 80 of the 190 oral and poster presentations and all abstracts from the plenary sessions and the concurrent sessions. Abstracts in Spanish are included. Topics include climate change in the Sky Island Region, southwestern cienegas, the Northern Jaguar Reserve, amphibian conservation, biodiversity of plants and animals, fire effects, grasslands, and human impacts, and tools. The conference hosted a symposium about Santa Cruz River Watershed Conservation. A lively open forum at the end of the conference generated a list of future scientific and management needs for the Madrean Archipelago and a commitment to increase international cooperation. Mexican participants graciously offered to host the next conference. Speakers stressed the importance for all interested parties to collaborate--to work side-by-side and constantly inform one another about relevant research, timely events, and cross-pollination opportunities throughout the region.

Keywords: Madrean Archipelago, Sky Islands, southwestern United States, northern Mexico, natural environment, fauna, flora, research, management, biodiversity, climate change

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Merging Science and Management in a Rapidly Changing World:

Biodiversity and Management of the Madrean Archipelago III

and

**7th Conference on Research and Resource Management in the
Southwestern Deserts**

**May 1–5, 2012
Tucson, Arizona**

Compilers

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Preface

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Spanning four states in two countries, the Madrean Archipelago or Sky Island region has been a puzzle and an inspiration to researchers and managers for more than a century. Gradients of species diversity include a north/south axis for influences from the Sierra Madre Occidental and Rocky Mountains, an east/west axis for influences from the Chihuahuan and Sonoran Deserts, and vertical gradients from valley grasslands or desert scrub to mountain-top communities. Overlying that is a fascinating cultural and political diversity created by an international boundary that bisects the region.

The first Conference on Biodiversity and Management of the Madrean Archipelago, held in 1994, focused on defining the region. The assembled experts described different aspects of this collection of “sky islands” that form an “archipelago” off the “mainland” of the Sierra Madre. From about 100 presentations, we learned that this region is special to people from many disciplines and many walks of life. We recognized the need to collaborate across disciplines and across borders.

The 1994 conference served several important functions. It established the state of our knowledge about the region, and led to a proceedings volume (DeBano and others 1995) that became a widely cited reference. Beyond that, it created a shared understanding of the similarities and differences across this distinct biogeographic area.

At the second conference, in 2004, we went deeper into understanding the region. We focused on connections: between mountains and valleys, between people and the landscape. Through 160 presentations, we looked at big patterns of diversity, in both species and ecological processes (Gottfried and others 2005).

This volume of proceedings resulted from the third conference in this series, held in 2012. This time we had 190 presentations, with a stronger representation from Mexico than ever before. The presentations, and the papers in this volume, reflect various attempts to adapt to a region that is undergoing rapid and accelerating change. Changes along the border between Sonora and Arizona have disrupted the movement of animals and damaged the sense of shared culture across that border. Technology is evolving, giving us new insights. Species distributions are shifting, challenging our best efforts at conservation. And the climate is changing around us.

The 1994 conference had one talk about the anticipated effects of climate change. In 2004 we had seven. This year we have 21 climate-change talks, and yet barely skim the surface of the work that is underway.

We’ve also had an explosion of information about biodiversity in this region. At previous conferences, many people recognized big gaps in our knowledge about the mountains of Sonora. Now there is a great new book summarizing biodiversity of Sonora (Molina and Van Devender 2010). And there is the Madrean Archipelago Biodiversity Assessment, a bi-national effort to compile everything known about species distributions in the region and to conduct new biological inventories.

In 1994, jaguars were thought to be extinct in Arizona. That changed in 1996, with photographs of two different, apparently healthy jaguars in the Peloncillo and Baboquivari Mountains of Arizona. The 2012 conference included a half-day symposium to discuss what’s been learned in

the new jaguar reserve in Sonora, new models for jaguar habitat use, and how that knowledge can be applied for jaguar conservation across the Sky Island region.

Clear evidence of the cooperation and collaboration by many organizations and individuals to achieve a common goal of strong biodiversity and sound management of the Madrean Archipelago is apparent by the members of the conference organizing committee:

- Cecil Schwalbe, Conference Chair, U.S. Geological Survey
- Dale Turner, Program Chair, The Nature Conservancy
- Acasia Berry, Sky Island Alliance
- Emily Brott, Sonoran Institute
- Alejandro Castellanos, Universidad de Sonora
- Cori Dolan, University of Arizona
- Peter Ffolliott, University of Arizona
- Gerald Gottfried, USDA Forest Service, Rocky Mountain Research Station
- Bill Halvorson, University of Arizona
- Philip Heilman, USDA Agricultural Research Service
- David Hodges, Cuenca los Ojos Foundation
- Larry Jones, USDA Forest Service, Coronado National Forest
- Tom Van Devender, Sky Island Alliance
- Christina Vojta (ret.), U.S. Fish and Wildlife Service
- Claire Zugmeyer, Sonoran Institute.

On behalf of the organizing committee for the Third Conference on Biodiversity and Management of the Madrean Archipelago, we invite you to explore the articles collected in this proceedings volume. If you find things of interest, we encourage you to share them broadly, and to contact the authors with questions and ideas. Most of these papers are works in progress and probably do not represent the final word. It is our hope that they serve, instead, as the beginning of many fruitful conversations and additional studies.

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A Special Thanks

Bill Halvorson

The organizing committee for the Madrean Archipelago III conference offers a special thanks to William L. Halvorson for his significant contributions to our knowledge of natural resources in the Southwest and especially for his dedication in helping produce the Madrean Archipelago conferences and other regional, national, and international meetings over the past two decades. He has long championed his belief that knowledge unshared is knowledge lost.



Bill came to Tucson in 1992 with the National Park Service as Leader of the Cooperative Park Studies Unit on the University of Arizona campus. He began organizing conferences originally for the National Park Service to bring scientists and managers together to share new knowledge of biological and cultural resources on southwestern park lands. In 1998, he was awarded both the Rocky Mountain Region and National Natural Resources Research Award of the National Park Service. He, along with research scientists in the other Department of the Interior agencies, was transferred to the National Biological Survey, which eventually became the Biological Resources Discipline within the U.S. Geological Survey. Bill soon expanded these biennial conferences to include other agencies and organizations to the extent that he was one of the co-chairs of the Madrean Archipelago II conference in 2004, which was also the fifth in the series of his biennial meetings on Research and Resource Management in the Southwestern Deserts.

Bill Halvorson was one of the organizers of the Society for Ecological Restoration, serving as Treasurer for 4 years and serving on the Board of Directors for 13 years. He has also served as program chair for a series of international Ecological Restoration Conferences in Florida, California, Spain, Australia, and Mexico. He is currently working on the 2013 conference, which will be SER's 25th Anniversary Meeting in the birthplace of ecological restoration, Madison, Wisconsin.

Bill has been an important advisor to us in organizing this Madrean Archipelago III conference. We thank him for his contributions to science and management of biological and cultural resources in the North American Southwest (including northern Mexico), his wise counsel, and his friendship.

Having retired from Federal Service, Bill can be contacted at sustainableolutions@mind-spring.com.

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Biodiversity and Management of the Madrean Archipelago III: Closing Remarks and Notes from the Concluding Session

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During the first week of May 2012, the Third Conference on Biodiversity and Management of the Madrean Archipelago brought together more than 300 people with an interest in this region. It included scientists, land managers, activists, and land owners from both sides of the international border. After three and a half days of presentations, the participants gathered for a moderated discussion of major issues for biodiversity and management. They were also asked to suggest ways in which people could build stronger collaborations. The following is a summary of those discussions, with minor additions to add context.

International Border

We work at an ecotone of ecoregions, policies, and countries where many things change when you cross the international border. The borderlands form a mixing zone, different from both countries. The past decade has brought new challenges to collaboration and management for biodiversity across the border. The barbed-wire fence became a steel wall in many places, blocking the movement of wildlife (Córdova and de la Parra 2007; Flesch and others 2010). New social barriers were created by anti-immigrant legislation in Arizona, migrant and drug-related problems in Sonora and Chihuahua, and tougher regulations for legal trans-boundary movement.

Despite those influences, useful collaborations continue and new opportunities exist. Several good examples were presented at the conference, including riparian restoration on both sides of the border in San Bernardino National Wildlife Refuge and Rancho San Bernardino, and a bi-national conservation planning workshop for the Santa Cruz River. In addition to strong representation at this conference from Mexico and the United States, about 17% of the presentations included authors from both countries. Participants mentioned a large and growing population of biology students in Mexico, creating new opportunities for collaboration. It was also mentioned that private land owners in Mexico are much more open than Americans to having people work on their land, and are more likely to make small management changes if they know that others care.

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Bi-National Coordination and Sharing Information

The Madrean Archipelago conference series has been a useful way to share knowledge between those who attend, and the proceedings from these conferences have been good reference works. However, land managers, decision makers, and the general public often do not read such technical reports and may not be aware of their existence. Conference attendees can make a big difference by sharing the results with others, both within and beyond their organizations. The information could be even more useful if it were summarized for particular audiences, with the major new information put into a regional context.

There is also great potential for putting new information into practice on the ground, by finding ways to demonstrate the results to land owners and land managers. It is not enough to just tell them how to do something; showing them a technical report is not helpful. We need to demonstrate how conservation can work for the land and for people.

For researchers and technical staff, there is a need for consistent data sets across the region. This includes the need for basic GIS data such as vegetation, elevation, and streams. In some cases, the data may be available but not widely known, such as a recent North American mapping of biotic communities (Brown et al. 2007; www.peter.unmack.net/biotic). Several presentations at this conference featured the new regional database of plant and animal records compiled as part of the Madrean Archipelago Biodiversity Assessment (Van Devender and others, *The Madrean Archipelago biodiversity assessment*, this proceedings), valuable information on biological diversity for Sonora (Molina-Freaner and Van Devender 2010), and the ambitious national data sets prepared for Mexico by CONABIO (www.conabio.gob.mx).

The Madrean Archipelago framework provides an excellent opportunity for developing more innovative ways to increase coordination among organizations, researchers and students. Increasing interest and student participation in Mexico can help build stronger ties between research organizations on both sides of the border. Many participants recognized the need for more cross-border meetings, particularly attending meetings held in Mexico. While that might reduce participation from the United States, it would increase Mexican-U.S. collaborative participation. Some suggested that the next Madrean Archipelago conference should be held in Sonora. Others noted the growth of a student-run biology conference held annually at Universidad de Sonora in Hermosillo, and invited U.S. researchers to participate. There was also the first announcement of a conference on biology and management of the Sierra Madre, planned for Durango in 2014. Participants were also hopeful that improvements in video conferencing could make cross-border meetings easier. Beyond that, small

workshops or trainings held more frequently could build relationships and spread knowledge without a lot of work. And the knowledge transfer needs to go both directions, north and south, because there are leaders in research and management on both sides of the border. We consider that an extra effort should be developed in the coming years to provide ways to build stronger links between institutions, in particular among students and colleagues.

Many participants felt that bad news about the border region was exaggerated. They mentioned the challenge getting a positive media story about good collaborative work, and suggested a need to work harder at sharing positive news, which might include sending stories to the media, requesting fair coverage, or independently distributing news through the Internet.

Volunteers

Increasing the use of volunteers in research and monitoring is a trend that needs to continue in this era of tight budgets. Participants mentioned that an aging U.S. population means a growing pool of potential volunteers with extensive knowledge and skills, soon to include many attendees at this conference. Those volunteers can sometimes make a greater impact if they don't just rely on managers to identify volunteer needs, but instead help managers understand what the individual volunteers can provide. Managers can also increase the number and variety of their volunteers, both young and old, by making it easier to get help from someone who has time available. In particular, a web site could be developed to publicize volunteer research opportunities.

Future Conferences

The last Madrean Archipelago conference had a substantial cultural resource component, while this conference included only two papers. Cultural resources provide a tie to the land and can help in the conser-

vation process. Native nations need to be included as well; they also manage lands and have different perspectives to offer. Preparation for future conferences should include reaching out to the cultural resource communities and bringing those voices into the mix.

Conclusions

The challenges of merging science and management in a rapidly changing world cannot be solved in a 4-day conference, but require strong coordination through time between disciplines and across borders. The presentations at this event included results from collaborative projects that began at previous Madrean Archipelago conferences. We look forward to the next conference, and to learning the new discoveries that began with conversations in the hallways at this event.

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Plenary Sessions

National Wildlife Refuge Management on the United States/Mexico Border

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***Abstract**—Many conservation strategies have been developed by the U.S. Fish and Wildlife Service in cooperation with others to protect habitat and enhance the recovery of fish and wildlife populations in the San Bernardino Valley, which straddles Arizona, United States, and Sonora, Mexico. Habitats along this international border have been impacted by illegal activities, frustrating recovery of rare species. In addition, potential threats to national security have prompted the United States to aggressively control the country's boundaries, thus creating additional challenges for land managers mandated with protecting the nation's landscapes, natural resources, and associated values. Such challenges are not insurmountable and, with focused coordination, resource management and border security can be achieved and can often compliment one another. With or without the influence of changes along the international border, an effective species recovery strategy must include a coordinated approach that involves assessing the biological requirements of selected species through combinations of inventory, monitoring, and research activities; managing and protecting existing and historic habitats and populations; assessing potential reintroductions of key species into appropriate habitats where feasible; managing exotic plants and animals that threaten the recovery of desired conditions; and providing outreach and education relative to the species, their habitats, and the ecosystems upon which all fish, wildlife, and humans depend.*

Introduction and Management Context

The U.S. Fish and Wildlife Service (Service) manages the 2,369-acre San Bernardino National Wildlife Refuge (SBNWR) and the 2,765-acre Leslie Canyon National Wildlife Refuge (LCNWR) located in southeast Arizona's Cochise County adjacent to the international border with Mexico. Both refuges were established under the authority of the Endangered Species Act of 1973 and the Fish and Wildlife Act of 1956 in order to "...conserve fish or wildlife which are listed as endangered species or threatened species...or plants." The refuge landscapes support a documented high diversity of species including at least 493 plants, 332 birds, 67 mammals, 43 reptiles, 13 amphibians, 8 fish, 77 dragonflies and damselflies, 130 butterflies, and over 450 bees.

The primary role of SBNWR and LCNWR is to sustain and recover the native fish of the Río Yaqui Basin (USFWS 1994), which is a large watershed that drains portions of southeastern Arizona and southwestern New Mexico in the United States, and eastern Sonora and western Chihuahua in Mexico. This geographic region is well known for containing enormous biological wealth on both sides of the border (Brown and Kodric-Brown 1996; Sayre and Knight 2009; Van Schoik and others 2006), and cooperative efforts between the

Service and environmentally sensitive landowners in the United States and in Mexico are implementing conservation strategies to protect and restore land and water sources, promote applicable monitoring and research, and reintroduce and maintain self-sustaining fish and wildlife populations (Austin in press; USFWS 1995). Properties are being managed in ways that acknowledge that they are all simply parts of the bigger landscape necessary to perpetuate a healthy mix of plants, fish, and wildlife within the region. Management and restoration efforts are viewed in the context of the entire landscape with a view beyond individual ownership boundaries or the international border. Such a view helps maintain habitat integrity across boundaries, a critical need for wildlife migration and dispersal.

Environmental restoration by government agencies and private landowners is ongoing in this region, and specific goals and objectives of such efforts on both sides of the border in the San Bernardino Valley are focused primarily on maintenance of open space and sustainable restoration of ecological relationships in such a way that the residents of the region may continue a productive rural lifestyle. Wetland restoration throughout the watershed is benefitting populations of all wetland dependent species by increasing the availability of seasonal and permanent water, by increasing the overall quality and quantity of water, and by lessening the potential for erosive scouring of wetlands during extreme flood events. Watershed function of uplands is also being enhanced, positively impacting the entire landscape along with the fish, wildlife, and human populations that they support. An example of these efforts is the ongoing grassland restoration and stream restoration being implemented on Rancho San Bernardino in Sonora. This project is allowing native fish like Mexican stonerollers (*Camptostoma ornatum*) to re-colonize upstream refuge wetlands without the need for active reintroductions.

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Balancing Border Security And Conservation

The San Bernardino Valley is attractive to people for reasons other than its natural biodiversity. SBNWR, LCNWR, and adjacent lands are isolated wildland areas adjacent to the U.S./Mexico border that have become arteries for human trafficking and narcotics smuggling organizations. Such activities are sometimes a hazard to landowners, resource managers, and area visitors because immigrants and smugglers have become increasingly violent and determined to continue their illegal activities. The problem is not just the movement of people and drugs, but includes related illegal activities (Billington and others 2010) such as vandalism, arson, accidental wildfire, property damage, burglary, theft, assault, and even murder conducted by both northbound and southbound people. In response to escalating security concerns, the U.S. Border Patrol (USBP) is aggressively enforcing laws to deter and prevent illegal activities and apprehend smugglers. This effort has promoted national security and has also benefitted the environment by helping reverse the adverse environmental effects of illegal border activities.

Unfortunately, enforcement of illegal activities along the border may also result in incidental property damage and adverse impacts to environmental and cultural resources (Cohn 2007; Christen and Matlack 2009; Duncan and others 2010; Forman and Alexander 1998; Sayre and Knight 2009; Segee and Neely 2006; Shepard and others 2008; Trombulak and Frissell 2000). Aggressive border security measures may affect endangered species and their habitats when it becomes necessary to clear vegetation, which may in turn alter natural water flow, reduce water absorption and infiltration, and impact aquifer recharge capacity. Operation of vehicles off established roadways or across wetlands and flowing streams may discharge petroleum products or other pollutants, increase siltation within perennial and seasonal streams or washes, and accelerate erosion and mobilization of fragile hydric soil types characteristic of the region. Each of these impacts may also negatively influence recovery of endangered plant species by increasing the potential for soil particles to become airborne during dry periods, potentially affecting air quality, vegetation transpiration, and pollination. Terrestrial endangered species may be impacted through crushing or other direct mortality (Glista and others 2009; Lalo 1987; Romin and Bissonette 1996). Aquatic species may be affected by increasing siltation of streams and other wetlands following major precipitation events. These events may result in higher than normal levels of erosion and siltation, which potentially affects oxygen availability, gill function, and reproduction. Illegal activities and their undesirable impacts on the environment are not new; for at least the past 100 years the San Bernardino Valley has been used as a travel route for smugglers and illegal immigrants. However, since about 2001, numbers of illegal immigrants, smugglers, and USBP agents have increased dramatically. Therefore, illegal border activities and the enforcement to control those activities remain threats to resource management and species recovery efforts on SBNWR and LCNWR.

An effective balance can be achieved between the U.S. Department of Homeland Security (DHS) mission of protecting U.S. borders and the U.S. Department of Interior (DOI) mission of protecting natural and cultural resources. SBNWR staff have been active partners with USBP and Immigration and Customs Enforcement (ICE) in planning and implementing national security ever since the refuge was established. More recently, increased cooperation between the Service, USBP, and ICE personnel has additionally enhanced safety, national security, and natural resource protection. Through such cooperative efforts, many of the damaging impacts of illegal activities and

required enforcement have been avoided, minimized, or mitigated. This cooperative effort is exemplified by the work of Service law enforcement officers who function as environmentally sensitive force multipliers serving national security and land management objectives in a cost effective manner. At SBNWR and LCNWR, the Service is assisting with national security efforts and has an effective strategy for monitoring, preventing, and controlling illegal activities by securing refuge boundaries, controlling access, and halting illegal immigration. Service law enforcement officers play an important role in monitoring human access on Refuge lands by using a system of remote seismic sensors and cameras, by patrolling for illegal activities and looking for footprints, by regularly communicating with USBP agents through an improved radio system, and through joint patrol work.

It has become routine for Fish and Wildlife Officers to work with USBP to conduct enforcement activities on and adjacent to Refuge lands and in areas having sensitive natural resources. The Service and USBP have been demonstrably proactive in ensuring that national security and environmental protection are not mutually exclusive objectives, and such cooperation has been very effective, resulting in a decrease of illegal activities occurring on the Refuges. For example, “unofficial” USBP statistics show an average apprehension rate of about two individuals per month on SBNWR for the period October 2011–April 2012; down significantly from 2010, when “unofficial” USBP statistics depicted an average of 142 individuals apprehended each month on SBNWR (USBP, unpublished data).

SBNWR and LCNWR are enclosed by fences, allowing controlled public access that is limited to daytime use only. Most of the south SBNWR boundary is protected by a wildlife permeable vehicle barrier to protect sensitive wetlands, and has been completely effective in preventing vehicle incursions onto the refuge from Mexico since its construction in 2005. Trail cameras and other tactics are used to document and monitor wildlife use of riparian corridors and wetlands, and also identify and document illegal human activities occurring on the refuges. Habitat restoration is being accomplished to benefit wetland, upland, and riparian-dependent species. Refuge pond construction and stream restoration make human travel through mud and water difficult, so wetlands tend to be avoided by those engaged in illegal activities. Grassland restoration is being accomplished through prescribed burning and removal of invasive mesquite trees, providing benefits to resident and migratory wildlife and also removing cover once used by smugglers, increasing visibility across the landscape, and therefore deterring illegal activities. Existing administrative roadways are maintained to increase refuge management efficiency and also to promote effective law enforcement, detection, monitoring, and deterrence of illegal activities. These roadways are being upgraded with base coarse material to provide all weather use and to minimize soil particle movement into the air or into adjacent wetlands. Many roads are remotely monitored by seismically sensitive equipment to help track human activity timing, and by video surveillance cameras to help identify refuge users. Refuge staff and heavy equipment routinely maintain portions of the border road within the Roosevelt Reservation adjacent to SBNWR to ensure passage by USBP agents through areas prone to frequent flooding and sediment deposition.

Many USBP activities have further enhanced Refuge protection and endangered species recovery. For example, USBP operates Mobile Surveillance System equipment in the San Bernardino Valley to help interdict illegal activities, and this equipment is located in off-refuge areas that maximize the deterrence of illegal activities throughout the Valley without negatively impacting refuge lands. Additionally, DHS contractors have surfaced many border roads used by USBP with material that allows all weather vehicle travel and limits dust and sediment transfer into the environment. USBP has allowed grasses to

grow within the 60-foot Roosevelt Reservation rather than attempting to maintain this easement as a corridor that is completely free of vegetation. The original international border fence was not very wildlife permeable, consisting of an eight-strand barbed wire barrier reaching up to 5-feet tall. This barrier altered cross-border movement of wildlife, though some species were capable of moving over or under the barbed wire fence, or of utilizing existing breaks in the fence that allowed easier passage. Construction of vehicle barriers immediately adjacent to the existing barbed wire border fence further reduced wildlife movement. Mule deer (*Odocoileus hemionus*) that often seemed willing to jump the barbed wire fence would not attempt to jump the enhanced obstacle of a barbed wire fence combined with a vehicle barrier. The removal of the barbed wire fence by USBP, other agency personnel, landowners, and volunteers has greatly benefitted cross-border wildlife movement (Sayre and Knight 2009).

Several environmental concerns were favorably addressed by DHS and their contractors by installing vehicle barriers designed so that wildlife movement would not be obstructed; investigating and protecting cultural resources from potential damage; conducting construction during winter to avoid impacts to nesting birds and to avoid periods of heavy, erosive rainfall; and reseeding some disturbed areas to prevent sheet erosion and promote the growth of native grasses. A substantial bridge was constructed by DHS contractors across Black Draw to provide vehicular access along the border within the Roosevelt Reservation while also minimizing negative impacts to the perennial stream and associated species. These examples illustrate that DHS officials are committed to working with SBNWR personnel to minimize disturbance to the refuge, to protect the environment, and to protect endangered species. Not all of the foreseeable environmental impacts related to the congressional mandate of maintaining national security could be minimized or eliminated, so DHS officials collaborated with the Service to identify solutions for potential environmental problems created by the infrastructure, and DHS committed to funding up to a total of \$50 million through January 2018 to support various environmental projects to be split among California, Arizona, New Mexico, and Texas. These projects demonstrate some positive approaches toward reconciling national security and environmental objectives along the international border.

DHS-Funded Environmental Projects

Work on many DHS-funded environmental projects has been initiated on and adjacent to SBNWR (USFWS 2011). A concrete fish barrier in Black Draw near the border is being designed and will be constructed to allow downstream movement of native fish but will prevent upstream migration of non-native fish species. This is the best available option for achieving segregation of native fish from predatory exotic fish occurring downstream in Mexico. A series of shallow wetland units have been constructed, and will help maximize biodiversity and optimize the production of self-sustaining populations of native fish and wildlife. The construction and placement of multiple rock-filled wire cage erosion control gabion structures is being accomplished in key locations throughout the watershed to catch water-borne sediments being transported during precipitation events, improve the landscape's ability to halt and slow the scouring erosive impacts of seasonal flood flows, more effectively catch and hold precipitation runoff to provide water for fish and wildlife, help restore groundwater recharge in the shallow aquifer, allow increased soil stabilization, and ultimately help enhance vegetation corridors for wildlife movement. Construction debris deposited by contractors in several San Bernardino Valley staging areas during vehicle barrier construction has been removed and these areas have been seeded with

native grasses to help control the density and spread of non-native vegetation that could otherwise become invasive and dominate the landscape. Two separate irrigation wells on and adjacent to SBNWR were drilled to ensure adequate water quantity and quality capable of enhancing populations of federally listed species: Yaqui chub (*Gila purpurea*), Yaqui topminnow (*Poeciliopsis sonoriensis*), Yaqui catfish (*Ictalurus pricei*), and San Bernardino springsnails (*Pyrgulopsis bernardina*) located in the area on both public and private lands. The Service and DHS are also working collaboratively with the University of Arizona to monitor Río Yaqui fish species and their habitats on and adjacent to SBNWR to assess their population status and evaluate the potential affects of sediment mobilization into wetlands. Each of these environmental projects, supported financially by DHS, is important to recovery of listed species in the United States and Mexico.

Rare Species Recovery Strategy Inventory, Monitoring, and Research

With or without the influence of changing human activity or land use along the international border, effective recovery of rare species must include coordinated assessments of the biological requirements of selected species through combinations of inventory, monitoring, and research. Refuge staff and collaborators are monitoring species population trends and conducting research to identify management actions that will support species recovery in efficient and cost effective ways. Various refuge monitoring projects are providing information that may be useful in assessing the effects of various border impacts on wildlife populations, and these projects can each function to produce data used by border managers in multiple ways by (1) determining the presence, absence, and relative abundance of species and serving to provide basic inventories and baselines upon which to compare against in the future; (2) documenting use of habitat types by various target species and identifying important wildlife movement corridors between Arizona and Sonora; (3) documenting the dynamics and long-term changes in wildlife use of habitats; (4) determining the impacts of border related activities on habitat use by animal populations; (5) identifying areas of potential conflict between humans and wildlife; and (6) evaluating the impacts that illegal human activities have on plant and animal populations and on animal movement patterns. For example, to learn more about the groundwater aquifer conditions and trends relative to climate change or other influences within the Leslie Creek and San Bernardino Valley watersheds, monitoring wells have been installed to provide a continuous record of water levels on both private and Refuge lands. This data has provided information concerning groundwater and surface water relationships in the watershed, has substantially increased an understanding of the hydrology of Leslie Creek, and shows a declining trend in the level of the aquifer at LCNWR likely related to declining winter precipitation in the Chiricahua Mountains (Broska 2009a).

Monitoring wells in the San Bernardino Valley are documenting that groundwater levels have been raised in some locations (Broska 2009b), and the Río San Bernardino now flows continuously and perennially from north of the U.S. border on SBNWR southward across Rancho San Bernardino to well beyond Mexican Highway 2. To help determine hydrological relationships among individual springs, ponds, and wells on SBNWR and the adjacent privately owned Johnson Historical Museum of the Southwest (Slaughter Ranch), Refuge staff is collecting samples and analyzing water chemistry. This data will benefit management of federally listed species while also providing information for Slaughter Ranch managers and visitors on the safety of consuming the water.

Partners conduct annual monitoring of native fish populations on both sides of the border, and on both private and Refuge lands, to determine and document fish health, fecundity, and population trends. Population monitoring of other federally listed species, such as the Huachuca Water Umbel (*Lilaeopsis schaffneriana* var. *recurva*), the Cochise pincushion cactus (*Coryphantha robbinsorum*), the Chiricahua leopard frog (*Lithobates chiricahuensis*), and the San Bernardino springsnail is accomplished periodically to help document the recovery of these species, to identify threats, and to increase our understanding of ecological associations (Malcom and others 2005; Varela-Romero and Myers 2010).

Long-term monitoring of breeding bird species is being accomplished at both SBNWR and LCNWR to provide data on population and demographic parameters for targeted species. The information collected is providing a better understanding of the productivity, survivorship, and population trends of avian communities on the refuges. Basic long-term reptile and amphibian population monitoring is being conducted on these Refuges to help document species richness, understand ecological trends, investigate population dynamics and the roles of rare species, and to help support resource management decisions. SBNWR and LCNWR serve a large assemblage of wildlife species and provide important landscape features in the form of linear riparian areas. The use of such riparian corridors by large mammals is not well documented (Bennett 1990; Laurance and Laurance 1999). Increasing human activities and development in the San Bernardino Valley might be expected to impact the natural movement and behavior of large mammals, and wildlife movement corridors are expected to become even more important, making our better understanding of these areas crucial to effective management.

Habitat and Population Management and Protection

Managing and protecting existing and historic habitats and wildlife populations is being accomplished by the Service and conservation partners using a variety of effective mechanisms, including the Endangered Species Act Safe Harbor Program, Habitat Conservation Planning for rare species, Service challenge cost share agreements, acquisition of conservation easements, rights-of-ways, memorandums of understanding, and other collaborative approaches. Such cooperation is expected to increase in helping recover native plants, fish, and wildlife as funding become more limiting. These mechanisms provide a framework for establishing creative partnerships with the ultimate goal of reducing conflicts between listed species and planned activities on both public and private lands. For example, the impacts of climate change for the southwestern United States are anticipated to include higher temperatures and lower levels of precipitation. These changes will dramatically impact the ecology of the region. Wildlife migration routes may change, making it important that landscapes and the crucial corridors that interconnect private, state, and federal lands be protected and enhanced, along with the fish and wildlife populations that they support. A coordinated approach to management activities that compliment all the landowners in the San Bernardino Valley must be progressive and recognize the unique needs of each partner.

Species Reintroductions

When managing the recovery of rare plants and animals, it is often important to assess potential reintroductions of key species into ap-

propriate habitats, and this is occurring on and adjacent to SBNWR and LCNWR. The Service has an ongoing program of reintroducing federally listed threatened or endangered fish including the Yaqui chub, Yaqui topminnow, beautiful shiner, and Yaqui catfish into suitable habitats on private and public lands in the Río Yaqui watershed. A major positive step in the recovery of the Chiricahua leopard frog is being accomplished through an effective partnership between the Service, Arizona Game and Fish Department, U.S. Forest Service, and the American Museum of Natural History's Southwestern Research Station near Portal, Arizona. LCNWR is one of the last sites in southeast Arizona where Chiricahua leopard frogs occur naturally in the wild; however, this protected habitat for the frog is rapidly disappearing because increased extreme drought conditions are leaving the Refuge without flow in Leslie Creek. Tadpoles were therefore transported from LCNWR to Southwestern Research Station facilities where they were raised in a controlled environment and their progeny are then being released back into suitable habitat in the Chiricahua Mountains. The endemic San Bernardino springsnail currently exists in multiple isolated metapopulations in both Arizona and Sonora, with such populations further fragmented by the international border. This rare species is being helped through restoration of appropriate wetland habitat on Slaughter Ranch and SBNWR. Once adequate habitat is in place, springsnails from adjacent metapopulations will be restored to areas they once populated without human intervention.

Non-Native Species Management

Introduction of non-native plants and wildlife into environments where they did not occur naturally can have devastating effects on native populations (Bazzaz 1986; Courtenay and Stauffer 1984; D'Antonio and Vitousek 1992; McLaughlin 2002; Rosen and Schwalbe 1996; Rosen and Schwalbe 1998; Scott 1992). This is the case with the Asian tapeworm (*Bothriocephalus acheilognathi*) and bullfrog (*L. catesbeiana*), both of which are now established in the San Bernardino Valley. The Asian tapeworm is adversely affecting recovery of rare cyprinid fish species (Kline and others 2007). Populations of the Chiricahua leopard frog, lowland leopard frog (*L. yavapaiensis*), and Mexican garter snake (*Thamnophis eques*) have all experienced severe decline or have even been eliminated in the area as a result of bullfrog depredation (Rosen and Schwalbe 2002).

Continuing efforts are made by trained Refuge staff and volunteers to control the spread of non-native species from Refuge lands, however, total control will never be achieved given the complexity of the landscape and the widespread establishment and abundance of these species in the area. Fortunately, the vast majority of plant species in the area are natives, leaving the ecosystem relatively free from exotic plant invaders. Nonnative plants that are a current concern to Refuge managers include Russian thistle (*Salsola iberica*), Johnson grass (*Sorghum halapense*), Lehmann's lovegrass (*Eragrostis lehmanniana*), Malta starthistle (*Centaurea melitensis*), giant reed (*Arundo donax*), salt cedar (*Tamarix ramosissima*), and buffleggrass (*Pennisetum ciliare*). The existence of all these species requires regular monitoring and control to reduce their spread and their resulting negative impacts to the recovery of rare native species. In some cases, if nonnative species were to establish themselves on the Refuges, restoration work being done would be severely compromised. Given the difficulty and expense of controlling non-native plants and animals once they have established themselves in an environment, efforts must focus on preventing the initial introduction of such species.

Outreach and Education

Under the National Wildlife Refuge System Improvement Act of 1997, national wildlife refuges offer several “priority public uses,” including hunting, fishing, wildlife observation, wildlife photography, environmental education, and interpretation when such activities are compatible with the purpose for which the refuge was established. Arizona’s Cochise County is a major international tourist destination due primarily to the region’s interesting human history and also because of the region’s unique and abundant natural history. SBNWR and LCNWR are two of the few refuges administered by the Service that were created specifically to protect rare native fish. Protection of this border region and restoration of associated fish and wildlife habitats and populations in both the United States and in Mexico by private landowners, conservation organizations, and government agencies including DHS will help ensure that the ecological balance that has been effective for centuries will continue to provide the conditions necessary for all fish, wildlife, and humans dependent upon the Río Yaqui Basin.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Biodiversity in the Madrean Archipelago of Sonora, Mexico

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Introduction

Flowery rhetoric often gives birth to new terms that convey images and concepts, lead to inspiration and initiative. On the 1892-1894 expedition to resurvey the United States-Mexico boundary, Lieutenant David Dubose Gaillard described the Arizona-Sonora borderlands as “bare, jagged mountains rising out of the plains like islands from the sea” (Mearns 1907; Hunt and Anderson 2002). Later Gaillard was the lead engineer on the Panama Canal construction project.

In 1951, Weldon Heald, a resident of the Chiricahua Mountains, coined the term ‘Sky Islands’ for the ranges in southeastern Arizona (Heald 1951). Frederick H. Gehlbach’s 1981 book, *Mountain Islands and Desert Seas: A Natural History of the US-Mexican Borderlands*, provided an overview of the natural history of the Sky Islands in the southwestern United States. The ‘desert seas’ in the valleys are desert grassland and Chihuahuan desertscrub in the north, Sonoran desertscrub to the west, and foothills thornscrub in the south. Variants of the term include Sky Island region (McLaughlin 1995; Gottfried and others 2005; Skroch 2008), sky-island ranges (Felger and Wilson 1995, Fishbein and others 1995), and sky island bioregion (Fishbein and others 1995; Skroch 2008). Today we mostly use ‘Sky Island Region’ with capital letters. The best name in Spanish is *Islas Serranas*, rather than the literal translation *Islas del Cielo*, because *cielo* means both ‘sky’ and ‘heaven.’ The analogy to oceanic islands (Warshall 1995) is limited because Sky Islands differ from true insular areas in high species diversity, low local and regional endemism, and low percentages of non-native species (McLaughlin 1995). While any isolated area is a potential area for speciation in small populations, there are relatively few species restricted to the Sky Island Mountains.

The term ‘Madrean’ comes from the Sierra Madre. The Mexican Plateau is a vast area of grasslands and desertscrub between the Rocky Mountains in New Mexico and ca. 1,300 km to the south the Trans-Mexican Volcanic Belt in south-central Mexico. The Plateau is

open to incursions of frigid Arctic air from the north, and the Sierra Madres Oriental and Occidental create a double rain shadow and the Chihuahuan Desert. Madrean is a general term used to describe things related to the Sierra Madres. In a biogeographical analysis of the herpetofauna of Saguaro National Monument, University of Arizona herpetologist and ecologist Charles H. Lowe was probably the first to use the term ‘Madrean Archipelago’ to describe the Sky Island ranges between the Sierra Madre Occidental in Sonora and Chihuahua and the Mogollon Rim of central Arizona (Lowe, 1992). Warshall (1995) and McLaughlin (1995) expanded and defined the area and concept.

Biodiversity

In 2007, Conservation International named the Madrean Pine-oak Woodlands as a global biodiversity hotspot. This was a very large area that included the Sierra Madre Oriental in eastern Mexico, the Sierra Madre Occidental (SMO) in western Mexico, and the Sky Island ranges north of them into Texas, New Mexico, and Arizona. The Sierra Madre Occidental extends in western Mexico from Zacatecas and Jalisco north to Chihuahua and Sonora. The southwestern United States is famous for its diversity of animals and plants, and in many groups diversity increases southward in Sonora into the Sierra Madre Occidental and the New World tropics.

Species richness is enhanced in the Sky Island Region for many reasons. The western half of North America is mountainous, with topographically diverse habitats and vegetation zoned along elevational-climatic gradients. Biotic communities are concentrated in small geographic areas compared to the eastern United States where vegetation mostly changes along a north-south latitudinal gradient.

The Madrean Archipelago is a convergence zone for five biotic provinces (fig. 1). The Rocky Mountains and Colorado Plateaus to the north have temperate climates. In the mid-continent, the grasslands of the Great Plains extend from Canada south to New Mexico, Texas, and the Mexican Plateau. In the south, a mosaic with desert grassland in the valleys and Chihuahuan desertscrub on adjacent limestone slopes extends westward into southeastern Arizona and northeastern Sonora. On the western edge of the Sky Island Region, Sonoran desertscrub surrounds Sky Island ranges. In the south, more tropical oak woodlands and pine-oak forests are in the Sierra Madre Occidental and Sky Island mountaintops. In the lowlands, foothills thornscrub (FTS) and tropical deciduous forest are present. The transition between the New World tropics and the northern temperate zone is at about 29°N in

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

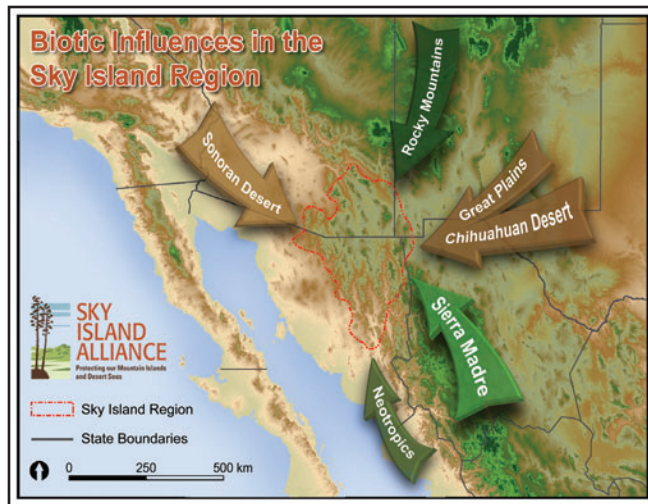


Figure 1—Map of the biotic convergence in the Madrean Archipelago (map by Nick Deyo).

east-central Sonora. The northern limits of FTS in Sonora are at about 30°11'N east of Sinoquipe in the Río Sonora Valley and 30°26'N at Presa Angostura on the Río Bavispe at the southern end of the Sierra El Tigre. FTS does not reach Arizona, but the distributions of quite a few FTS species cross the border into southern Arizona in desert grassland or oak woodland.

Sky Island Bioblitzes

Today the term 'bioblitz' is popular, meaning an intensive effort in a short period to document the diversity of animals and plants in an area. The first bioblitz in the southwestern United States was the 1848-1855 survey of the new boundary between the United States and Mexico after the Treaty of Guadalupe Hidalgo of 1848 ended the Mexican-American War. The border between El Paso, Texas, and the Colorado River in Arizona was surveyed in 1855-1856, following the Gadsden Purchase in 1853. Besides surveying and marking the border with monuments, these expeditions made extensive animal and plant collections, often by army physicians. Botanists John M. Bigelow, Charles C. Parry, Arthur C. V. Schott, Edmund K. Smith, George Thurber, and Charles Wright (fig. 2) and zoologist John H. Clark collected between the Santa Rita Copper Mines (= Silver City), New Mexico and Santa Cruz, Sonora in the modern Arizona-Sonora borderlands. On the second United States-Mexico Boundary Survey in 1892-1894, Edgar A. Mearns (fig. 3) collected 30,000 animal and plant specimens. The mammals were published in the book *Mammals of the Mexican Boundary of the United States* (Mearns 1907). In 1890, Norwegian Carl S. Lumholtz led an anthropological expedition through northeastern Sonora. He published a popular travelogue in 1902. Sweden's Carl V. Hartman was a botanist in charge of general biological collections (fig. 4).

Río Mayo-Yécora Baseline

In the 1930s, Howard Scott Gentry was a recent graduate from the University of California at Berkeley. In search of employment, he went to the New World tropics in the Álamos area in southern Sonora, in hopes of selling biological specimens to museum collections. His

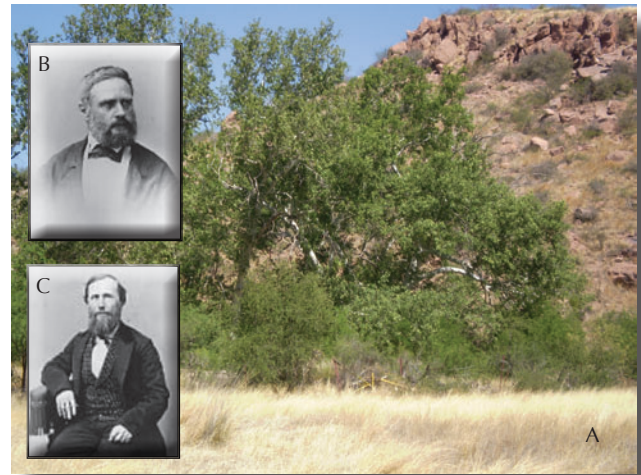


Figure 2—(A) The U.S.-Mexico Boundary and Gadsden Purchase Surveys of 1848-1857 went through Guadalupe Canyon (photo by T. R. Van Devender). (B) Arthur C.V. Schott and (C) Charles Wright were expedition botanists.



Figure 3—(A) The second U.S.-Mexico Boundary Survey in 1892-1894 was led by Edgar A. Mearns. (B) The Arizona-Sonora Boundary is between the Sierra San José and the Huachuca Mountains (photo by T. R. Van Devender).

plant collections were published in the book *Río Mayo Plants* (Gentry 1942). In the 1970s, 80s, and 90s, Paul S. Martin led expeditions from the University of Arizona, which retraced Gentry's travels, explored new areas, and resulted in a revision of the Río Mayo flora (Martin and others 1998). This large area includes the Sierra Madre Occidental in eastern Sonora and western Chihuahua.

Studies of the flora and fauna of the Yécora area in the SMO in eastern Sonora provide baseline information needed to compare biotas in the Madrean Archipelago with the mainland Sierra Madre Occidental, putting the biodiversity of Sky Island ranges in regional context. Mexican Federal Highway 16 (MEX 16), one of the few highways that crosses the SMO, provides a west-to-east elevational transect from the Río Yaqui (180 m) east to the Chihuahua border, 42 km east of Yécora (fig. 5).

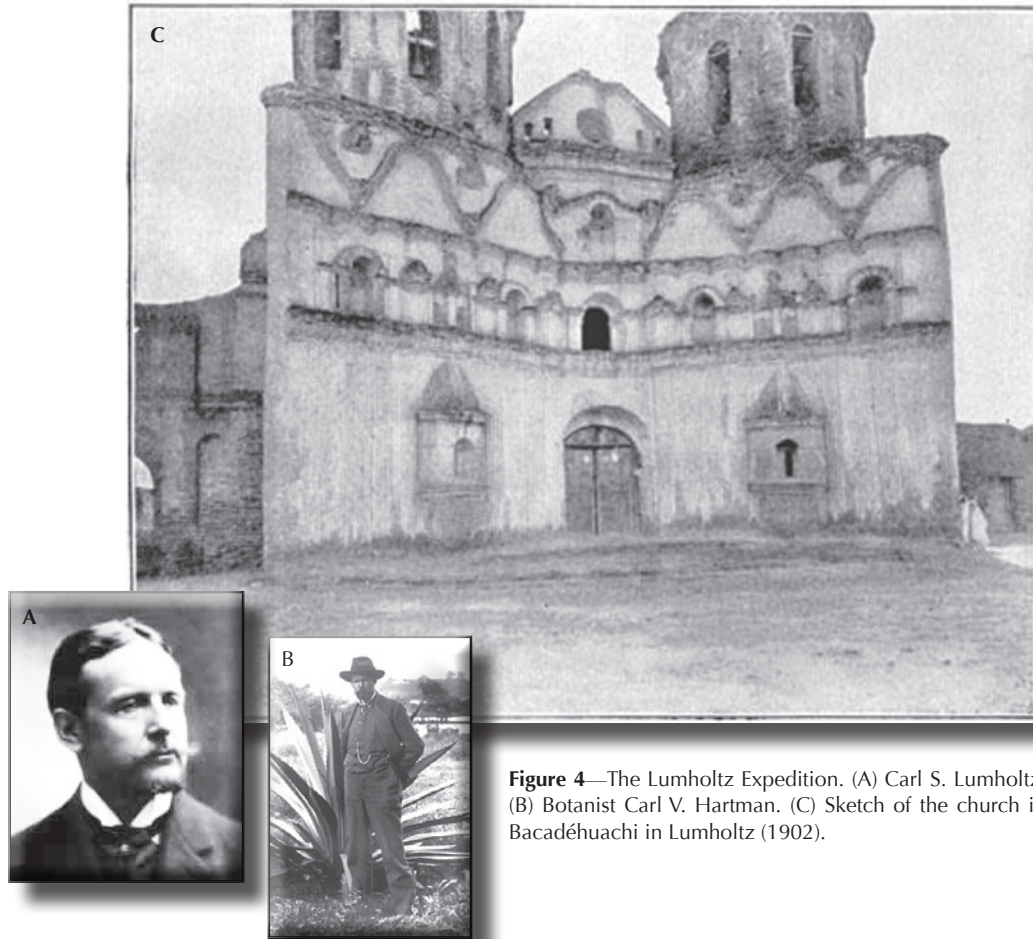


Figure 4—The Lumholtz Expedition. (A) Carl S. Lumholtz. (B) Botanist Carl V. Hartman. (C) Sketch of the church in Bacadéhuachi in Lumholtz (1902).



Figure 5—Sunset in the Sierra Madre Occidental west of Yécora, Sonora (photo by Erik F. Enderson).

Between 1953 and 2005, herpetologist-ecologist Charles H. Lowe collected amphibians and reptiles in the Yécora area for the University of Arizona Herpetological Collection on 33 trips involving 26 people. From 2004 to 2008, Erik F. Enderson and Robert L. Bezy documented the Yécora area herpetofauna through photography on 40 field days. Van Devender and Ana L. Reina-Guerrero at the Arizona-Sonora Desert Museum (ASDM) studied the flora of the Municipio

de Yécora region on 36 fieldtrips from 1995 to 2008. This flora with 1,776 taxa in 3,300 km² is very diverse, ca. 30% more diverse than the Huachuca Mountains in southeastern Arizona (Reina-G. and Van Devender 2005). There are 2,125 observations of 301 species of birds from the Municipio de Yécora in the Madrean Archipelago Biodiversity Assessment (MABA) database (<http://www.Madrean.org>).

Borderlands Exploration

Higher Sky Island mountain ranges such as the Sierras de los Ajos, Elenita, Marquita, and Tigre have extensive pine-oak forest and mixed-conifer forests on the highest peaks (fig. 6; Marshall 1957). The biotas of these areas are temperate mixtures of Sierra Madrean and Rocky Mountain species.

In the 1930s and 1940s, the University of Michigan had a very active biological exploration program in Mexico. In 1935, Barry Campbell collected amphibians and reptiles in the Sierra el Tigre, Sonora. From 1938-1941, Stephen S. White led three botanical expeditions to explore the Río Bavispe region of northeastern Sonora (fig. 7). The Río Bavispe flora with 1200 species (currently 995 taxa after revision) in 549 genera in 114 families from a wide range of habitats in the region was the first modern flora in the Sonoran borderlands (White 1948).

Ornithologist and intrepid explorer Joe T. Marshall studied the birds and dominant plants of pine-oak woodland in mountain ranges in southeastern Arizona, northeastern Sonora, and in the northern Sierra Madre Occidental in Chihuahua in the summers of 1951-1953

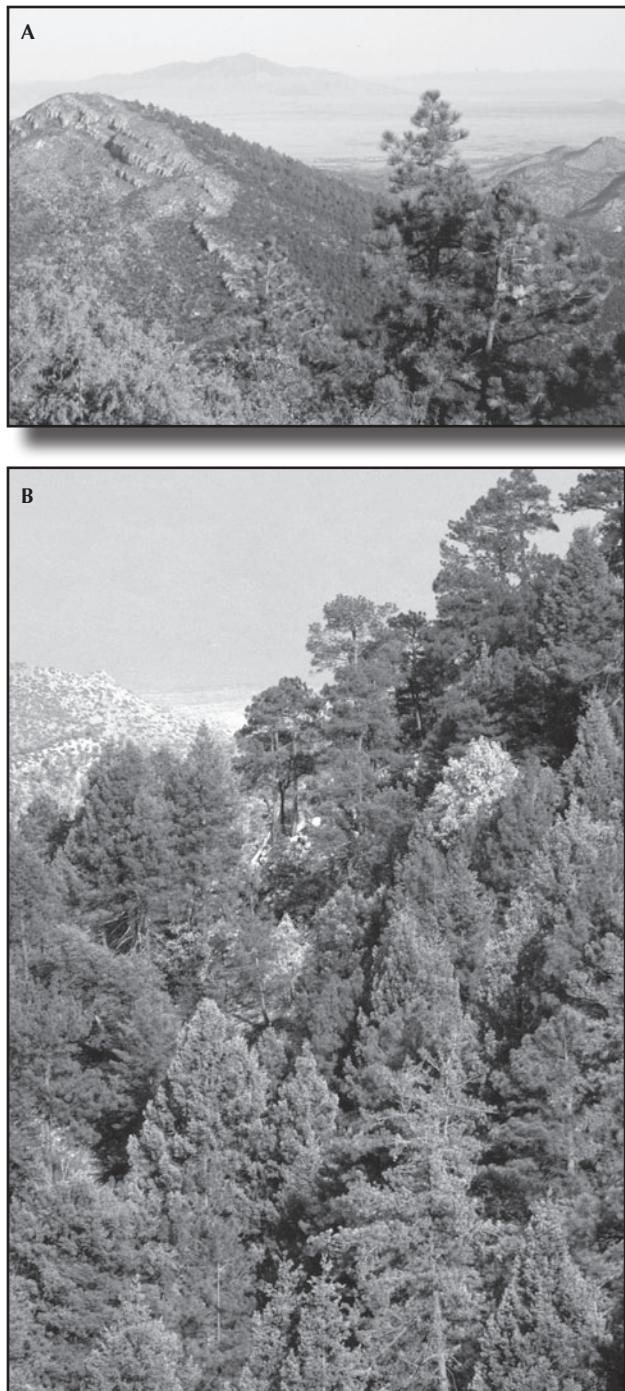


Figure 6—(A) View from the Sierra de los Ajos (photo by Dale S. Turner). (B) Mixed-conifer forest in Sierra El Tigre (photo by George M. Ferguson).

(Marshall, 1957). In Sonora, he worked in the Sierras Aconchi, Azul, “Cananea” (= Elenita-Mariquita), Oposura (= La Madera), and Pinitos.

Beginning in 1963, Raymond M. Turner, J. Rodney Hastings and later Tony L. Burgess made numerous trips to Sonora and Baja, California, to document the distributions of 414 species of plants in the Sonoran Desert. Their observations, collections, and ecological summaries were included in the book *Sonoran Desert Plants. An Ecological Atlas* (Turner and others 1995).



Figure 7—Stephen S. White and José Vera-Santos in the Sierra El Tigre on 13 October 1941.

Beginning in 1964, Stephen M. Russell and Gale Monson went to Sonora to observe birds on 150 trips and 692 field days. Their observations of 525 species were published in the book *The Birds of Sonora* (Russell and Monson 1998). Beginning in 2000, Aaron D. Flesch expanded on their field observations in northern Sonora (Flesch 2008).

In the 1980s and 1990s, the United States Fish and Wildlife Service, Área Natural Protegida (ANP) Ajos-Bavispe (a Comisión Nacional de Áreas Naturales Protegidas [CONANP) reserve), University of Arizona, and The Nature Conservancy Plant Collections organized expeditions to the Sierra de los Ajos just east of Cananea: Frank W. Reichenbacher in 1982, Paul S. Martin in 1983 and 1991, Peter Warren and Esther Saucedo in 1989, and Richard S. Felger, Mark Fishbein, George M. Ferguson, Dale S. Turner, James Malusa, Florentino Garza-S., and Martín Haro in October 1992 and July 1993 (Fishbein and others 1995). Turner, Garza-S., and Haro returned on a zoological expedition in 1998 along with Cecil Schwalbe, Taylor Edwards, Carl Olson, Yar Petryszyn, Dave Prival, and others (Alberti and others 1998).

With a few exceptions, documentation of animals and plants in the Arizona-Sonora borderlands was mostly neglected after the 1848-1857 and 1892-1894 boundary surveys. Even common, widespread species had not been collected or observed. Beginning in 2001, Van Devender and Reina-Guerrero (2005) began collecting and observing plants in *La Frontera*, the area in northern Sonora within 100 km of the Arizona border, as part of several inventory projects.

Leonardo Varela-Espinosa and Alberto Búrquez-Montijo at the Universidad Nacional Autónoma de México in Hermosillo studied the flora of the Sierra San Javier on seven trips from July 1996 to May 1997 (Varela-Espinosa 2005). The Sierra San Javier is the southernmost Sky Island with tropical deciduous forest below oak woodland. Since 1994, Herbario Universidad de Sonora (USON) has grown into a major regional collection. In 2003-2004, Curator J. Jesús Sánchez-Escalante, Manuel Espericueta-Betancourt, and Reyna A. Castillo-Gómez from USON, and Van Devender and Reina-Guerrero at ASDM studied the flora of the Sierra de Mazatán (Sánchez-Escalante and

others 2005). This range is the southwestern-most Sky Island located 70 km east of Hermosillo in central Sonora. Between March 2009 and September 2011, Sánchez-Escalante, Denise Z. Ávila-Jiménez, David A. Delgado-Zamora, and Liliana Armenta-Cota from USON, and Van Devender and Reina-Guerrero at Sky Island Alliance studied the flora of Rancho El Aribabi in the Sierra Azul on seven field trips. El Aribabi Conservation Ranch in the Sierra Azul was designated an Área Natural Protegida Privada by CONANP in March 2011.

In July–August 2005, biologists from the University of Arizona and the Sonoran Desert Research Station inventoried the fauna and flora along the Río Áros, a tributary of the Río Yaqui in east-central Sonora (O'Brien and others 2006). Participants included Charles O'Brien, Aaron D. Flesch, Eric Wallace, Michael D. Bogan, Samia Carrillo-Percástegui, Sky Jacobs, and Charles van Riper III.

In April–May 2008, Sky Island Alliance organized an expedition to the Sierra El Tigre to observe plants and animals (Avila-Villegas and Jacobs 2008). Participants were Sergio Avila-Villegas, Paul Condon, Sky Jacobs, Matt Skroch, Robert Villa, Rodolfo Villa, and landowners.

Madrean Archipelago Conferences

As recently as two decades ago, few people knew of the Madrean Archipelago as a distinct region and the evidence for its importance was scattered among many disciplines in two countries. In September 1994, a conference entitled *Biodiversity and Management of the Madrean archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico* was organized by the Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, along with Sky Island Alliance (DeBano and others 1995). There were 69 presentations and 20 posters. The second Madrean Archipelago Conference in May 2004 was entitled *Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago*. There were 93 presentations and 14 posters. The lack of information from the Sky Island Region in Mexico was noted in both conferences.

In May 2012, the third Madrean Archipelago conference assembled the current state of our knowledge about the unique natural and cultural resources of the Madrean region and continued the discussion of management practices useful for maintaining those resources with 24 sponsoring organizations. It brought together researchers, partners in resource stewardship, land managers, educators and students, government officials, consultants, and the interested public from both sides of the border to examine the Madrean Archipelago of the southwestern United States and northwestern Mexico. There were 151 presentations and posters, including substantial advances in the knowledge of animal and plant distributions in Mexico.

Madrean Archipelago Biodiversity Assessment

One of the conclusions of both of the Madrean conferences was that there was an urgent need for information from the Mexican portion of the Sky Island Region. Sky Island Alliance was a principal organizer for both of these conferences. In spring 2009, the Northern Mexico Conservation Program at SIA initiated the Madrean Archipelago Biodiversity Assessment (MABA) project, in part funded by a grant from the Veolia Environment Foundation. The concept of documenting all plant and animal species in the Mexican Sky Island Region for use in conservation, land management, research, and education was proposed by former SIA Executive Director Matt Skroch, Dale Turner, and Aaron D. Flesch.

The online MABA database (<http://www.madrealn.org>) was created to make observations and images available to the public. The FLORA half of the database is directly linked to the Southwestern Environmental Information Network (SEINet) database, which has data for over 2 million herbarium specimens. The FAUNA half of the database was a new database. The MABA database differs from SEINet in that many records are observations rather than specimens, and that observations are often illustrated with color images. Historical records are from museum collections, literature, field notes and other databases. New observations are made on fieldtrips to remote high diversity Sky Island ranges. Study areas were selected based on the need for biological observations, conservation initiatives, and opportunities to collaborate with landowners, land managers, and local researchers.

While observations are made on all MABA trips, expeditions to high priority areas with 25–45 participants are especially productive. These are unprecedented groups of animal and plant specialists, landowners, agency biologists, university professors and students, journalists, photographers, and volunteers (fig. 8). In 2009–2011, there were five MABA Expeditions. In September 2009, 17 participants went to the Sierra San Luis on Cuenca Los Ojos Foundation property. In March 2010, 25 participants went to the Sierra El Tigre on private ranches within the ANPAjos-Bavispe. In August 2010, 39 participants, including professors and students from the nearby Universidad de la Sierra (UNISIERRA), went to the Sierra La Madera on private ranches, partially within the ANPAjos-Bavispe. In April–May 2011, 40 participants went to the Ciénega de Saracachi and the Sierra San Antonio. The Ciénega is an important wetland natural area on Rancho Agua Fría that was proposed as an Área Natural Protegida Estatal by the Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES) in 2010. The Sierra San Antonio is privately owned. In August 2011, 45 participants went to the Sierra Bacadéhuachi, which is mostly privately owned. Rincón de Guadalupe, owned by the Catholic Diocese of Hermosillo, has excellent potential for protection as a natural area.

The MABA database is the primary source of biological records for the state of Sonora. FLORA contains 112,623 Sonoran observations, including 20,606 from MABA, 20,331 from the book *Sonoran Desert Plants. An Ecological Atlas* (Turner and others 1995), and 13,285 from the Comisión para el Uso y Conocimiento de la Biodiversidad (CONABIO). FAUNA contains 128,843 Sonoran records, including 60,856 from MABA, 39,022 from the book *The Birds of Sonora* (Russell and Monson, 1998), 33,993 from the eBird database, and 27,404 from CONABIO. Species numbers in the MABA database provide preliminary diversity estimates for the Madrean Archipelago in Sonora. There are ca. 2880 plant taxa in northeastern Sonora. Insects are very diverse, but only 1380 taxa are documented in the Sky Islands Region. Vertebrates are better represented: fish (39 species), amphibians and reptiles (104 species), birds (358 species), and mammals (76 species). Surprisingly, diversity appears to decrease southward, but it probably reflects the north-northwest to south-southeast orientation of the ranges, and decreasing area and fewer biological inventories to the south.

Conclusions

The MABA project has pulled together information from biological expeditions in the Madrean Archipelago from the last 160 years. The knowledge of plant and animal distributions has increased dramatically since 1950, reflecting fieldwork by American botanists, herpetologists, ornithologists, and mammalogists, the development of biology programs at the Universidades de Sonora and de la Sierra,



Figure 8—MABA group at Rincón de Guadalupe in the Sierra Bacadéhuachi in August 2011 (photo by Chris Marzonie).

the CONABIO national biodiversity database, and the Sonoran state Área Naturales Protegidas program by CEDES. The 2010 book *Diversidad Biológica de Sonora*, edited by Francisco Molina-Freaner and Van Devender, summarized the state of knowledge of plants, animals, and vegetation in Sonora. These accomplishments are only the beginning—the opportunities for additional natural history studies in the Madrean Archipelago are enormous!

Acknowledgments

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Marshall, Edgar Mearns, John Lemmon, John Bartlett, and William H. Emory walked the biodiversity path long before us.

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Plenary Abstracts

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Climate change, megadroughts, and the North American monsoon. Climate change in the Southwest translates to changes in water availability, and records of past hydroclimate help us delineate the natural range of those changes. Past droughts are apparent in tree-ring based records and emerge from longer paleoclimate records as well. But do these droughts reflect changes in winter or summer moisture? This question is more than academic: as we move into a warmer world, we can expect generally drier winters and springs. But projections of future climate disagree with respect to changes in the North American monsoon, and global models do not yet simulate this system well. Here we use paleoclimate records to explore how summer rainfall has responded during past climate regimes. In this talk I will describe new results from cave-based climate records that demonstrate how, over the past 7000 years, the monsoon has clearly weakened. This result is consistent with other monsoon systems globally and with climate model simulations. I will explore implications for future hydroclimate regimes in our Southwest region.

El cambio climático, megasequías y el monzón norteamericano. El cambio climático en el Suroeste Norteamericano induce cambios en la disponibilidad de agua, y los registros ambientales hidrológicos nos ayudan a delinear el rango natural de esos cambios. Las sequías anteriores son evidentes en los registros de anillos de árboles (dendroclimatología) y también emergen de registros de paleo-climas más largos. Pero estas sequías, ¿reflejan cambios en la humedad de invierno o verano? Esta pregunta es más que académica: conforme el mundo se vuelve más cálido podemos esperar inviernos y primaveras más secas. Pero las proyecciones del clima del futuro no coinciden en los cambios en el monzón norteamericano y los modelos mundiales todavía no simulan bien este sistema. Aquí usamos registros paleo climáticos para explorar como las lluvias de verano han respondido durante regímenes climáticos anteriores. En esta charla describiré nuevos resultados basados en registros climáticos de cuevas para mostrar como los últimos 7000 años, el monzón claramente se ha debilitado. Este resultado es consistente con otros sistemas monzónicos mundiales y con modelos climáticos. Exploraré implicaciones para regímenes hidroclimáticos futuros en nuestra región del Suroeste Norteamericano..

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Floods, droughts, and aquatic biodiversity in the Madrean Archipelago. The Madrean Sky Island region harbors a rich variety of aquatic habitats, ranging from mountain streams to lowland rivers and ciénegas. Compared with other regions, MSI aquatic habitats are unusual because they are patchily distributed across the landscape and strongly influenced by seasonal flooding and drought. This fragmented spatial arrangement coupled with strong disturbance dynamics has shaped both the evolution and ecology of MSI aquatic organisms. Many aquatic insects, fish, and riparian plants are now known to possess adaptations for surviving extreme events such as flash flooding or prolonged drought. Additionally, population genetic studies have revealed marked evolutionary divergence of aquatic populations at fine spatial scales. In one case, populations of an aquatic invertebrate predator have evolved unique behaviors to escape flash floods, and these behavioral adaptations differ in response to local canyon-scale flood regimes. Disturbance dynamics and spatial isolation also facilitate high aquatic invertebrate biodiversity within a surprisingly small amount of habitat, with largely distinct communities coexisting within meters of each other. This fine-scale partitioning of genetic and species diversity is a double edged sword. Although changes in hydrologic regime due to climate change, groundwater pumping and other factors have eliminated unique populations and communities, the diversity and adaptability of these organisms could provide resilience to ecological change.

Inundaciones, sequías, y biodiversidad acuática en el Archipiélago Madreño. La región de las Islas Serranas Madreñas alberga una gran variedad de hábitats acuáticos, desde los arroyos de montañas a los ríos y ciénegas de la tierra baja. Comparados con otras regiones, los hábitats acuáticos de la región Madreña son diferentes por estar fragmentados y bastante influenciados por inundaciones y sequías de estación. Esta fragmentación espacial combinada con fuertes dinámicas de disturbio ha influenciado la evolución y ecología de los organismos acuáticos de la región Madreña. Ahora se sabe que muchos insectos acuáticos, peces y plantas ribereñas están adaptados para sobrevivir eventos extremos, como son las crecidas o sequías prolongadas. Además, estudios genéticos poblacionales han revelado una marcada divergencia evolutiva de las poblaciones acuáticas en escalas espaciales pequeñas. En un caso, las poblaciones de un depredador invertebrado acuático han evolucionado comportamientos únicos para escapar de las crecidas, y estas adaptaciones conductuales difieren en repuesta a los regímenes locales de inundaciones a escala del cañón. Las dinámicas de perturbación y aislamiento espacial también facilitan una alta biodiversidad de invertebrados acuáticos en un hábitat sorpresivamente pequeño, con comunidades muy distintas coexistiendo separadas por unos cuantos metros. Esta división en una escala pequeña de diversidad genética y de especies es una espada de doble filo. Aunque los cambios en el régimen hidrológico debido al cambio climático, extracción de agua subterránea y otros factores han eliminado poblaciones y comunidades únicas, la diversidad y adaptabilidad de estos organismos podría aumentar la capacidad de recuperación del cambio ecológico.

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Riparian vegetation and disappearing groundwater. Over the past century in the southwestern United States, rapid economic growth, expanding urban centers and agriculture have driven steep increases in freshwater demands, which have been met through groundwater pumping, surface flow diversions, and dams - all of which alter water availability and flow patterns in rivers. These shifting baseline conditions, combined with episodic drought, have led both to the drying of river reaches that were once perennial as well as to the wetting of previously dry river segments. Drawing from case studies of rivers in southern Arizona including Cienega Creek, Garden Canyon, the San Pedro River, and the Santa Cruz River, we explore several scenarios: 1) the biological changes that occur in groundwater-dependent ecosystems as water tables deepen and no-flow periods increase, 2) the patterns and rates of vegetation change that occur when diversion and pumping pressures are reduced; and 3) the response of riparian vegetation to discharge of municipal effluent into stream channels.

Vegetación ribereña y desaparición de aguas subterráneas. Desde el siglo pasado en el suroeste de Estados Unidos, el rápido crecimiento económico, la expansión de los centros urbanos y la agricultura han aumentado la demanda de agua dulce, que se ha resuelto a través de bombeo del acuífero, desviaciones de corrientes en la superficie y presas, todo lo cual altera la disponibilidad de agua y los patrones de las corrientes de ríos. El cambio de estas condiciones básicas, combinado con la sequía, han llevado tanto al secado de tramos de ríos que antes eran perennes, y también ha causado que tramos anteriormente secos tengan agua. A partir de estudios de caso de ríos en el sur de Arizona, incluyendo los ríos Ciénega Creek, Garden Canyon, San Pedro, y Santa Cruz, exploramos varios escenarios: 1) los cambios biológicos que ocurren en los ecosistemas que dependen de aguas subterráneas, conforme baja el nivel freático y aumentan los períodos sin corriente, 2) los patrones e índices de cambio de vegetación que ocurren cuando se reduce el estrés por la desviación y el bombeo, y 3) la respuesta de la vegetación ribereña a la descarga de aguas residuales en los cauces de arroyos..

The content of these abstracts reflect the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Santa Cruz River Conservation

Conservation Efforts and Possibilities for Increased Collaboration in the Santa Cruz River Watershed

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Abstract—Attendees of the annual Santa Cruz River Researchers' Day meetings have identified a need to expand collaboration, partnership, and sharing of lessons learned across the watershed. To help guide this interest, Sonoran Institute organized a symposium on 2 May 2012 entitled "Santa Cruz River Conservation." The symposium had simultaneous Spanish/English translation and featured (1) presentations of work being done within the watershed in Mexico, (2) a binational mapping session to inventory current knowledge of conservation efforts in the watershed, and (3) a discussion and invitation to consider forming an interim watershed-wide steering committee. Featured themes included: the importance of strong community engagement and relationship building for conservation success, highly valued areas are often located in highly threatened areas, and increased watershed-wide collaboration could provide numerous benefits and help ensure greater collective impact. Participants were actively engaged and many will volunteer to form an Interim Santa Cruz River Steering Committee to begin brainstorming if and how to form a larger watershed-wide collaboration.

Introduction

Rivers and riparian areas in semi-arid regions support an abundance of life. The Santa Cruz River of southeastern Arizona and northwest Mexico supports tremendous diversity with nearly 600 species of plants and animals documented from a small stretch of the river at the Tumacácori National Historical Park (Powell and others 2005). The river has also supported human communities for thousands of years with evidence of human settlement dating to 9500-9000 B.C. (Logan 2002). In the past 60 years however, increasing demands for freshwater have led to significant groundwater pumping, dropping of water tables, and drying of many reaches (Glennon 2002), thus threatening the river's ability to sustain abundant biodiversity and provide ecosystem services that benefit human communities.

Numerous conservation efforts are underway throughout the Santa Cruz Watershed to promote watershed health and protect and restore these important riparian areas. In order to share results of research and lessons learned, an annual Santa Cruz River Researchers' Day was initiated in 2009. While initially focused solely on research and monitoring in the Upper Santa Cruz River, in Santa Cruz County, Arizona, partner interest in the event has grown and attendees have identified the desire to expand collaboration, partnerships, and sharing of lessons learned throughout the watershed, both binationally and across subwatersheds.

To help guide this growing interest in watershed-wide collaboration, the Sonoran Institute organized a featured symposium on Santa Cruz River Conservation on May 2, 2012. This symposium consisted of three sessions featuring (1) presentations of projects conducted in the Mexico portion of the watershed, (2) an inventory of conservation efforts throughout the watershed, and (3) a discussion and invitation to consider forming a watershed-wide steering committee. To reduce language barriers, simultaneous translation of English and Spanish was available throughout the day.

Santa Cruz River Through Mexico

Most Mexican partners have been unable to attend the annual Santa Cruz River Researchers' Day due to expense and challenges associated with the long distance travel. To begin increasing binational collaborations and sharing of lessons learned, Sonoran Institute invited researchers, managers, and individuals working on diverse conservation efforts within the Mexican part of the watershed to share their work during the first session of the symposium. Presentations included monitoring and restoration within the rural areas along the main stem of the river and efforts to improve watershed health within the city of Nogales, Sonora.

Rural Monitoring and Restoration

Upon leaving the headwaters in the San Rafael Valley in Arizona, the Santa Cruz River flows 25 miles (40.2 km) through several small ejidos or rural communities (Arizona-Sonora Desert Museum 2003). In addition to being the primary water resource for these small towns, the Santa Cruz River comprises a dominant portion of the water portfolio for the cities of Nogales, Sonora, and Nogales, Arizona, or "Ambos Nogales" (Sprouse 2003). Thus the river is recognized as an important resource, while simultaneously facing numerous concerns including

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overgrazing of rangelands, increased groundwater pumping, recurrent drought, and mining, among others (Solis and others 2012). To better understand changing river conditions, the University of Sonora led several studies over 15 years that examined surface and groundwater quality, surface water flows, and riparian vegetation (Solis and others 2012).

Water samples from the river and from wells that supply drinking water were periodically tested between 1996 and 2009 for many parameters including nutrients, agrochemicals, heavy metals, and microbial indicators (Solis and others 2012, 2011). Though many parameters met water quality standards, total coliforms, fecal coliforms, and *E. coli* were present in both surface and groundwater, with levels in the river exceeding the standards for many uses such as drinking water, recreation, and agriculture (Solis and others 2012). Microbial contamination of wells may be responsible for diarrhea in children, which represented 6.3% of illnesses along the Santa Cruz River in San Lázaro, Sonora (Solis and others 2012). Composition and abundance of riparian vegetation along the river were studied in 2000 (Solis and others 2012, 2002). The study documented 335 plant native species and 38 non-native species, with Cottonwood (*Populus fremontii*) and Gooddings' willow (*Salix gooddingii*) as the dominant species.

In addition to research, environmental education programs taught local students about water quality monitoring among other topics (Solis and others 2012). More funding is needed to continue these workshops, as well as to continue monitoring efforts along this stretch of the river. Continued sharing of lessons learned will increase research and conservation success.

Restoration efforts near San Lázaro, in the southern most portion of the Santa Cruz River watershed, have consisted of slowly building collaborations with local community members that eventually led to the installation of over 200 simple rock gabion structures in the mid-2000s (Murrieta and Hare 2012). These gabions slow water, build up soil, and create a "sponge" that will capture and slowly release the run-off, helping to restore degraded grazing lands (Murrieta and Hare 2012). Community involvement and celebration of all achievements, even the small ones, was emphasized as a critical element to restoration success. Sky Island Alliance is leading the preliminary planning phases of a new restoration project that will involve a collaborative effort with 4 to 5 local ranchers. The project would install fencing around riparian areas and establish pole plantings of cottonwood and willow to help mitigate erosion (Murrieta and Hare 2012). The fencing would exclude cattle and cross the river in some areas, requiring repair following large flood events.

Urban Watershed Health Improvements

Equally important for river health is managing and mitigating the quality of stormwater runoff generated in urban areas within the watershed. The impermeable surfaces associated with roads and other surfaces in urban areas quickly shed flows downstream and reduce infiltration of rainfall into the surrounding soil (Shipek and others 2012). Surface runoff in urban cities often carries pollutants that then flow directly into local rivers, impacting water quality. Rainwater harvesting and installation of other green infrastructure can reduce contamination, improve stormwater quality, and increase local infiltration (Shipek and others 2012). Local demonstration projects, completed with the community, simultaneously promote community awareness, train local leaders, and improve local stormwater quality.

Watershed Management Group has led the development of several demonstration sites in the Santa Cruz Watershed, including one at Instituto Tecnológico de Nogales (Shipek and others 2012). The

Instituto Tecnológico de Nogales campus is large and composed of many steep surfaces that quickly drain stormwater into major washes that eventually lead to the Santa Cruz River. Active and passive rainwater harvesting systems were installed to better utilize rainfall, while reducing and slowing stormwater runoff (Shipek and others 2012). Rainwater from the roof of a campus building was actively directed into a large cistern for landscape irrigation. Earthworks and berms slowed stormwater runoff allowing water to infiltrate and contaminants to be filtered out locally rather than flowing downstream. Together these rainwater harvesting features can capture 2.75 inches (6.99 cm) of rainfall in a 100-year storm (Shipek and others 2012). Community involvement is vital with these projects. The bulk of the volunteers participating in the construction were from local school groups, mainly students from the Instituto Tecnológico and students from schools involved in a grassroots effort called Asociación de Reforestación de Ambos Nogales (ARAN). In addition, partnership with Comisión Estatal de Agua, the state water agency, involves other levels of the community. Next steps for this project include development of evaluation and monitoring protocols as well as community workshops on maintenance of rainwater harvesting features.

Inadequate wastewater infrastructure can also lead to contamination of stormwater runoff. U.S. and Mexican economic policies have caused industrialization and rapid urban growth along the border, often with insufficient time and resources to build adequate public infrastructure (Lipnick and others 2012). Latrines and septic systems can overflow during flood events and directly contaminate washes and rivers through stormwater runoff, as well as cause health problems on both sides of the border. Limited water resources and insufficient wastewater infrastructure suggest the use of household composting toilets in Nogales, Sonora (Lipnick and others 2012). Composting toilets use little or no water to treat human waste and provide benefits including pollution control, production of compost, and reduced spending on water.

Building on a 2002 effort in Colonia Bella Vista, a collaborative multiphase project began in 2008 to install composting toilets within Colonias del Sol in Nogales, Sonora. University of Arizona's Bureau of Applied Research in Anthropology (BARA), has led this current effort with partnership from municipal officials and other community groups (Lipnick and others 2012). Community outreach and education is essential to the success of the project. Evaluations of the initial phase of toilet construction found that toilets were used properly (frequent use of toilet, sufficient sawdust) when people received outreach; those receiving inadequate outreach had toilets that were poorly maintained (e.g. smelly, not enough sawdust; Lipnick and others 2012). Community perception of composting toilets varies. Some members view composting toilets positively, while others think they are unpleasant. Several community members will connect to wastewater infrastructure and convert to flush toilets when that option is available, while others enjoy their composting toilet and have the secondary benefit of compost for their plants. Ideally, with continued outreach and education, a greater percentage of the community will choose composting toilets (Lipnick and others 2012). Current demand for composting toilets exceeds project capacity, with few resources to build new toilets and continue the monitoring of toilets from earlier project phases.

Community Participation Brings Success

A common theme identified, whether working in rural ranching communities or in densely populated urban settings of Mexico, was the importance of collaboration with local communities. Establishing relationships with community members by taking time to gauge their

interest, identify local problems, and develop collaborative solutions generated greater project success; however, finding adequate time and resources to build relationships is often a challenge. While achieving greater ‘buy-in,’ more importantly community involvement helps develop local skills and leadership that will be vital for long term success. Though a synthesis discussion primarily focused on the Mexican portion of the watershed, participants agreed that these ideas would apply within the U.S. portion of the watershed.

Binational Mapping

Mapping and inventory of current conservation efforts is an important tool and first step to help increase collaboration both binationally and across subwatersheds. The binational mapping session had several goals: 1) review draft maps of known conservation efforts, and 2) map and describe other conservation efforts, high value areas, and threatened areas. The mapping exercise focused on the upper half of the Santa Cruz River watershed and was further subdivided into four regions (fig. 1). The draft maps highlighted areas in the United States known to be either permanently protected for conservation or managed for conservation (e.g. Arizona State Trust Land that is managed for conservation use). As land ownership differs in Mexico, the existence of permanently protected areas is uncertain and could not be mapped. The draft maps also included general polygons identifying monitoring and restoration efforts. Each polygon was marked with a number that corresponded to a general description of the conservation effort and the lead organizations involved. Participants were asked to comment on existing polygons and descriptions, as well as draw

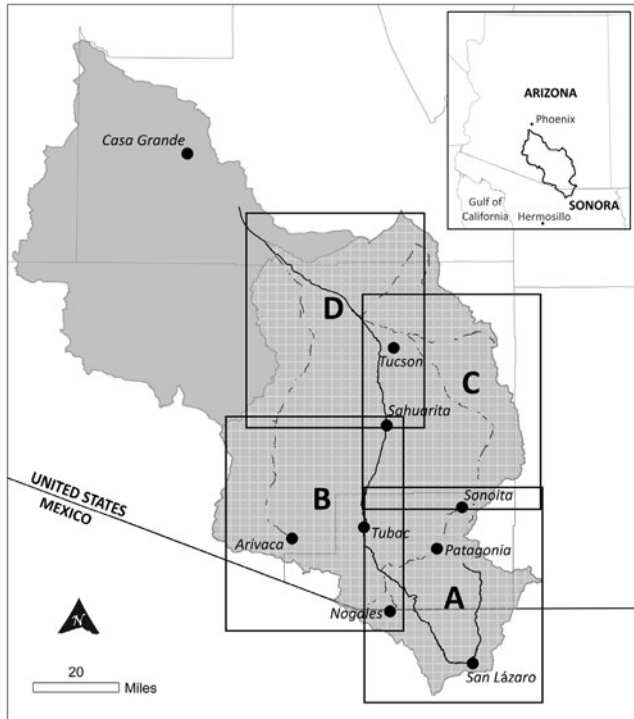


Figure 1—Orientation map depicting the locations of the four sub-regional maps (A-D) that were used to inventory conservation efforts within the upper half (hatched area) of the Santa Cruz River Watershed (grey area), Arizona and Sonora (Santa Cruz River = solid line, major tributaries= dashed line).

additional polygons associated with other conservation efforts. While primarily monitoring and restoration projects were identified in the draft map, the inventory of conservation efforts included the following: land protection, monitoring, research, restoration, coalition or partnership, or some other effort.

The 90-minute mapping session was an effective starting point to what will likely be a larger mapping effort in the future. There was good representation from all four subregions and numerous additions were made to the maps. Results of the mapping will be reviewed and eventually made available, with the idea that the datasets will be an active resource that is periodically updated.

Initial review of the mapping datasheets highlighted common themes among the different regions. High value areas included one or more of the following: perennial water, important ecosystems (i.e. grasslands, riparian), good wildlife habitat, and undeveloped areas or protection from development. Threatened areas often overlapped with areas of high value if there were known activities that may impact the high value area, such as loss of perennial flow to ground water pumping or mining activities. Other threats common to two or more of the sub-regional maps included mining, grazing, non-native species, and development.

Action Planning

The last session of the day was a facilitated discussion about increasing binational and subwatershed collaboration and the growing idea of forming a larger watershed entity for this purpose. Participants were asked to identify 1) the benefits and values associated with increased collaboration at the watershed level, and 2) the initial actions or first steps that would need to be taken.

Benefits to increased collaboration were numerous including: diversity of partnerships and perspectives; sharing of resources and lessons learned; leveraging of skills and expertise; greater knowledge of funding opportunities; continuity of conservation efforts; and greater efficiency of work so that duplication is avoided and projects are coordinated. In addition, a watershed-wide collaboration could provide greater recognition and visibility than single projects could on their own. A watershed-wide collaboration comprised of diverse groups and perspectives would demonstrate community buy-in for conservation efforts, which is vital to the region’s long term conservation success.

Energy was high with the interest clear and excitement palpable during the brainstorm session of possible actions for a watershed-wide collaboration to complete. The mission of a watershed-wide collaboration would need to be clearly defined and would likely be a first step should such an endeavor be undertaken. Defining the structure would also be important, as increased collaboration could range from a general alliance to a formal group. A watershed-wide strategic evaluation could examine long-term watershed health given current threats and issues faced, as well as identify the long-term stakeholders—the ‘hubs’ and ‘nodes’ of conservation efforts that will maintain the momentum. A strategic evaluation could additionally identify priorities, data gaps, and opportunities. Goals and benchmarks of success could be developed in order to measure long-term progress and collective success in the watershed. Other actions could include an annual celebration that could be based on existing events, not necessarily new ones. Community involvement is very important; utilizing existing events would likely be more successful than creating new ones.

Interest in a watershed-wide collaboration primarily stems from discussions at the annual Santa Cruz River Researchers’ Day. Though initially focused on the Upper Santa Cruz River, this event has expanded

to include other regions and could perhaps contribute to a watershed-wide collaboration. Participants were asked if they were interested in forming an Interim Santa Cruz River Steering Committee to continue discussions of how to increase collaborations and brainstorm if and how a watershed-wide collaboration might function. Sixteen attendees responded that they may be interested in participating in an interim committee; an additional 19 attendees of this year's Researchers' Day also expressed interest. Initial follow-up meetings and the formation of the interim committee will occur sometime in the summer or fall of 2012.

Conclusion

Organizing a symposium on Santa Cruz River Conservation within the Madrean Archipelago III conference provided numerous benefits including (1) elevating the importance of the conservation efforts in one of the Archipelago's binational watersheds, (2) providing an opportunity to highlight and discuss Santa Cruz River issues with an audience that may not participate in the annual Researchers' Day meeting, and (3) facilitating many logistical details such as simultaneous translation, venue, food, and audio-visual equipment. There were over 37 attendees of the symposium throughout the three sessions. More than 60% of attendees, including five from Mexico, did not attend this year's annual meeting on 29 March 2012. In evaluations completed at the end of the day, participants listed the collaboration discussions and opportunities to network and meet others working throughout the watershed as an important highlight of the symposium. Hearing presentations of work in Mexico was a big interest and much appreciated.

In preparation for this event, cost of attendance (single day registration \$110 U.S. or \$1,517 Mexican peso) was often given as a reason for not being able to participate. While there were numerous benefits to having the symposium within the Madrean Conference, future meetings will need to be free or much reduced in cost to maximize participation. Additionally, while travel stipends helped defray travel costs of some participants coming from Mexico, last minute schedule conflicts and presumably the cost of travel time amidst busy schedules, prevented several Mexican partners from attending. Fortunately, respective U.S. partners were able to present these binational conservation efforts, but participation by all partners is desired. Facilitating binational participation will continue to be a challenge to increasing watershed level collaboration. As presence of Mexican partners is still highly desired for future events, hosting meetings that alternate between the U.S. and Mexican venues, are closer to the border, or use video conference technology (i.e. Skype, GoToMeeting, or Google+) may need to be considered — suggestions that were also made during the final wrap-up session of the entire conference.

The Santa Cruz River Conservation symposium provided an initial inventory of conservation efforts and numerous ideas of how to increase collaborative efforts. Most importantly, the symposium helped build new and existing relationships that will advance the collective impact of conservation efforts watershed-wide.

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Changing Climate in the Sky Island Region

A Conceptual Model of Plant Responses to Climate with Implications for Monitoring Ecosystem Change

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Abstract—Climate change is affecting natural systems on a global scale and is particularly rapid in the Southwest. It is important to identify impacts of a changing climate before ecosystems become unstable. Recognizing plant responses to climate change requires knowledge of both species present and plant responses to variable climatic conditions. A conceptual model derived from observations made during a 28-year phenological study is presented and implications for monitoring ecosystem change are discussed.

Introduction

Climate change impacts are affecting natural systems world-wide (McCarty 2001; Parmesan and Yohe 2003). The rate of climate change in the American Southwest is more rapid than elsewhere on the continent, with the possible exception of the Arctic (Overpeck and Udall 2010). Increasing temperatures and decreasing precipitation in the Southwest are predicted by most climate models (Karl and others 2009; Weiss and Overpeck 2005; Sheppard and others 2002). Species currently present have had thousands of years to adapt to climate variability (Van Devender 1995, 2000), but the margin of continued success will become increasingly smaller as climatic change intensifies, particularly in non-mountainous biomes such as deserts and grasslands (Loarie and others 2009; Munson and others 2012). Resource managers are increasingly focusing on climate change in planning and management activities (USDI 2008; Heller and Zavaleta 2009; Mawdsley and others 2009). As the rate of change accelerates, it becomes important to identify when an ecosystem becomes unstable because mitigation efforts become more difficult and expensive as ecosystems near the point of collapse (CCSP 2009). Adequate monitoring is essential not only to detect changes but to identify appropriate adaptive management actions and to measure their effectiveness (Hobbs 2009; West and others 2009).

Plant Responses to Climate Change

Plants respond to climate change by moving, adapting, or dying (Peterson and others 2005). Movement is more likely than adaptation, but human uses may limit movement by reduction and fragmentation of habitat, as well as reduction in population sizes (Parmesan and others 2000). Climate variability *per se* may also limit movement (Early and Sax 2011). Adaptation is usually limited to the existing

genetic variability within a species; genetic shifts may mitigate local climate effects, but it is unlikely such shifts will mitigate impacts at the species level (Parmesan 2006; Huntley 2005; Thomas 2005). Dying or extinction is likely for species with low capacity for adaptation or dispersal (Walther and others 2002).

Expected responses of plants to climate change include (1) *phenological changes*, e.g., earlier onset of flowering, shortening or lengthening of growing seasons; (2) *geographic range changes*, e.g., range shifts, extensions, and contractions to higher elevations or latitudes; (3) *population and reproductive biology changes*, e.g., changes in abundance, reproductive success; and (4) *community and ecosystem changes*, e.g., changes in composition, habitats, productivity, structure (CCSP 2009; McCarty 2001; Parmesan 2005; Root and Hughes 2005; Walther 2010). Plants respond to climate change at the species, not community, level, and continued change will likely result in ecosystem destabilization and community shifts (Huntley 2005; Walther and others 2002). Ecosystems disintegrate and at the same time reassemble into new configurations at the species level (Lovejoy 2005). Predictions of what new configurations will develop are uncertain at best (Hobbs and others 2009) because the “rules” for assemblage of plant communities are not well understood (Gotzenberger and others 2012). Species’ interrelationships are largely unknown, and the loss of a single species may have cascading effects through and within trophic levels (Voigt and others 2003; Brooker 2006). Reduction in biodiversity may lead to loss of resilience, often in the form of shifts in dominant life forms, and this usually results in drastic transformation to an alternative and unpredictable state (Scheffer 2010). Scheffer and others (2001:596) conclude that “...efforts to reduce the risk of unwanted state shifts should address the gradual changes that affect resilience rather than merely control disturbance.”

Measuring Change in a Variable Climate

I have inventoried plant taxa in flower along a 5-mile route that climbs 4158 feet through six vegetative associations in the Finger Rock Canyon drainage in the Santa Catalina Mountains of Pima County, Arizona, since 1984 (fig. 1). The 1100-ac study area is about 0.6% of the area of the range but includes over 40% of the known plant taxa (Verrier, unpublished paper). During 1368 hikes in the drainage,

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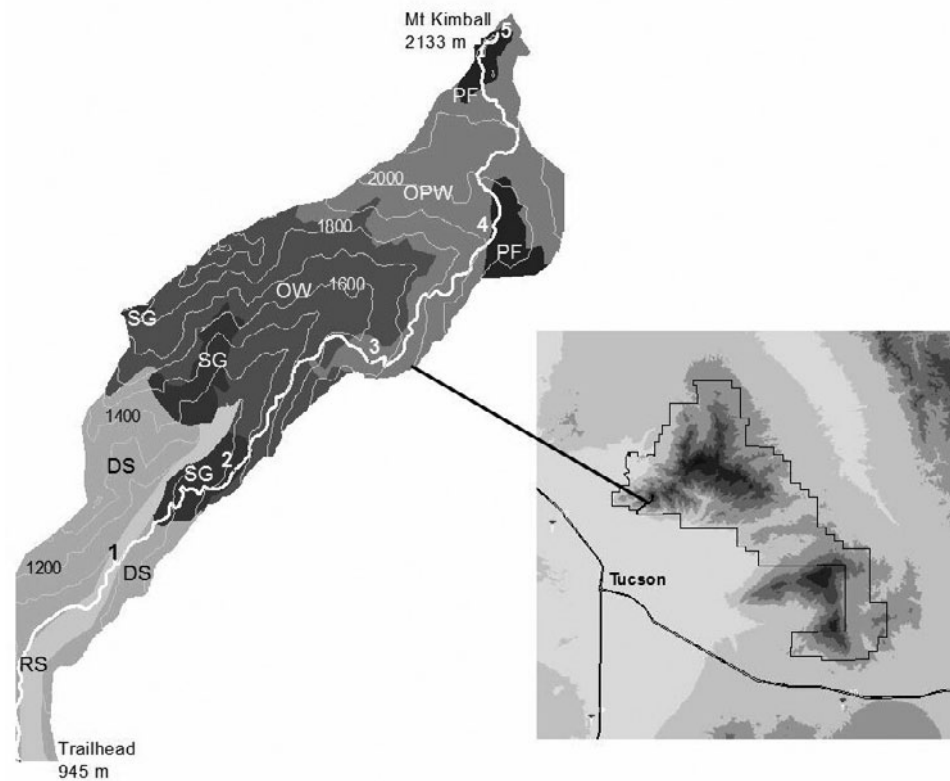


Figure 1—The study area, showing the route to Mount Kimball (white line) and the six vegetative associations. DS = desert scrub, RS = riparian scrub, SG = scrub grassland, OW = oak woodland, OPW = oak-pine woodland, and PF = pine forest. (Source: Jeff Belmat and Theresa Crimmins, based on data provided by the author.)

averaging once a week, I have recorded over 140,000 observations of 601 plant taxa by the mile segment on which they were seen.

Perhaps the most salient characteristic of the data shown in figures 2 and 3 is temporal and spatial variability that cuts across species and plant life forms, e.g., annual forbs, herbaceous perennials, shrubs, succulents, and trees. Species respond individually to the same climatic conditions. Presence or vegetative growth does not guarantee reproduction, and reproductive success can fluctuate widely. The distribution of most species in the flora is not only different from year to year but difficult to predict. In my experience, a basic tenet of much ecosystem monitoring—that key areas, study plots, or transects represent the broader community over time—assumes more homogeneity in composition, distribution, and frequency than exist in natural systems. Legendre and Fortin (1989:107) state “in nature, living beings are distributed neither uniformly nor at random. Rather, they are aggregated in patches, or they form gradients or other kinds of spatial structures.” No matter what the vegetative association, microhabitats within it differ significantly from the larger area, and a significant portion of the biodiversity of an area is found in them. Small differences in temperature or precipitation, or changes in aspect and slope, may change soil moisture and evapotranspiration, and therefore favor different species.

All of the specific responses to climate change listed above have occurred in my study area (Crimmins and others 2008, 2009). Although my data do not span a period of time sufficient to attribute these changes to climate change, the study area has experienced a severe drought accompanied by abnormally high temperatures since 1999

(Woodhouse and others 2010; Overpeck and Udall 2010) and plant responses to extreme climate events are likely indicative of responses to climate change (Parmesan and others 2000). In 2002, I began to notice significant mortality of dominant species in several vegetative associations, namely saguaros, white oaks, alligator junipers, and ponderosa pines. I began to look for other changes and quickly learned that a major indicator of change was what species were no longer present. Significant change, which I found is a combination of many changes at the species level, is not easy to see until a certain threshold is reached, even if expected species are well known and an area is visited regularly.

To recognize that plants are responding to climate change and to measure those responses, valid reference points with which to compare current conditions are prerequisite. First, knowledge of the area and local floras is essential (USDI 2009; USFWS 2010). Although not a substitute for comprehensive species inventories, historical data may be useful if interpreted in light of climate (Joyce and others 2008). Accurate mapping of vegetative associations can be useful in establishing parameters but without knowing what is or recently has been present, it is not possible to determine when or what species increase, decline, or disappear, and these are the species most likely to be the “early responders” to climate change. A decline in biodiversity is one of the most likely consequences of climate change (Bellard and others 2012). Biodiversity is a major component of ecosystem resiliency and, as Maestre and others (2012:214) state, “is crucial to buffer negative effects of climate change and desertification in drylands.” Resiliency may be reduced by gradual and difficult-to-detect changes in

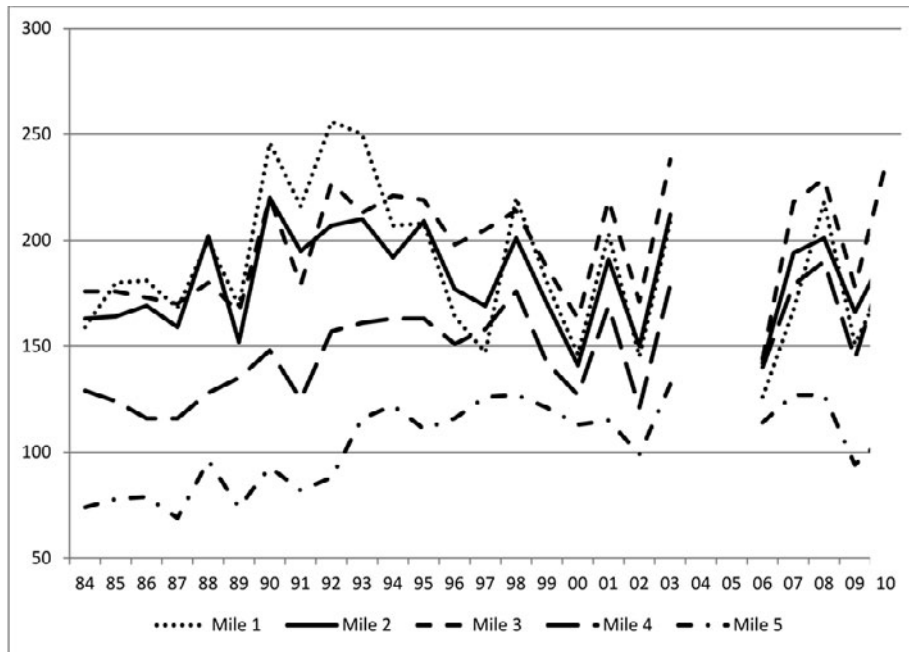


Figure 2—Number of species in flower by year and mile in the Finger Rock Canyon drainage, 1984-2010. Elevations are as follows: Mile 1 = 3100-3540 ft; Mile 2 = 3540-4500 ft; Mile 3 = 4500-5480 ft; Mile 4 = 5480-6360 ft; Mile 5 = 6360-7258 ft. (Data is incomplete for 2004-2005.)

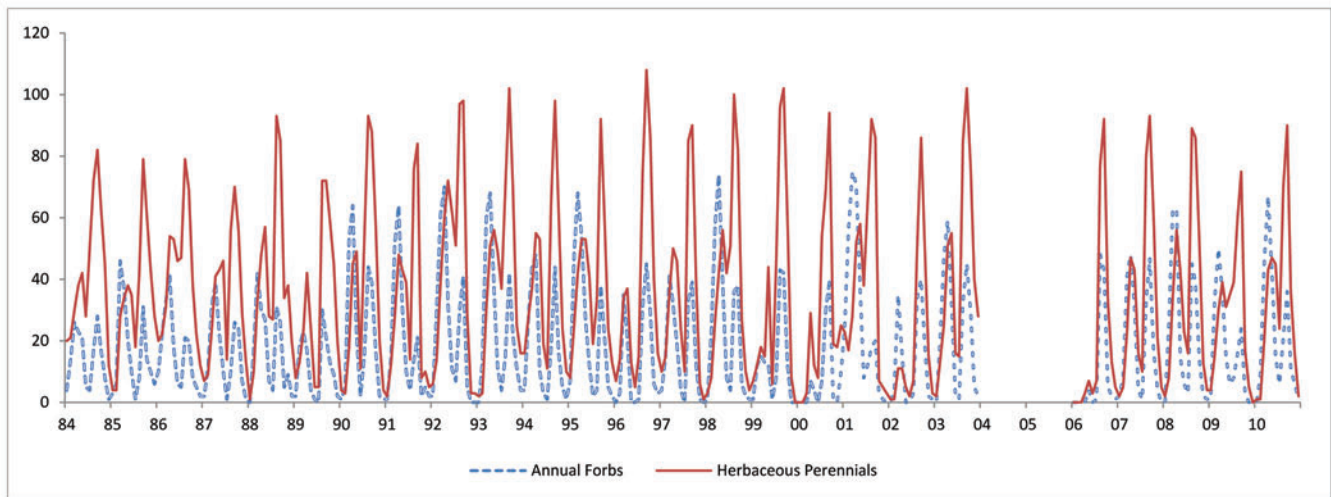


Figure 3—Number of annual forbs and herbaceous perennials in flower by month and year in the Finger Rock Canyon drainage, 1984-2010. (Data is incomplete for 2004-2005.)

environmental conditions to the point that natural fluctuations result in catastrophic ecosystem shifts, typically without early warning signs (Scheffer 2010). Early identification of responses to climate change must be made at the species level where such responses first appear. Focus at this level may also facilitate better understanding of plant-to-plant interactions (e.g., competition, facilitation, and adaptation) that can “mediate the impacts of environmental change” (Brooker 2006).

Second, a measure of “natural” or “expected” climate variability is required. If the response of individual species or groups of species to various climate change scenarios is to be determined, knowledge

of how they respond to climate variability at the species level is needed (Parmesan 2005; Peterson and others 2005). Precipitation and temperature are perhaps the most important abiotic drivers of plant reproduction (Crimmins and others 2008, 2010, 2011). No matter what climate change brings, climate will undoubtedly continue to be highly variable (fig. 4). The impacts of climate change can be difficult to discern even when looking at long-term data because there is so much year-to-year variability (Parmesan 2005). Assessments of abundance or frequency in particular are meaningless without knowledge of the

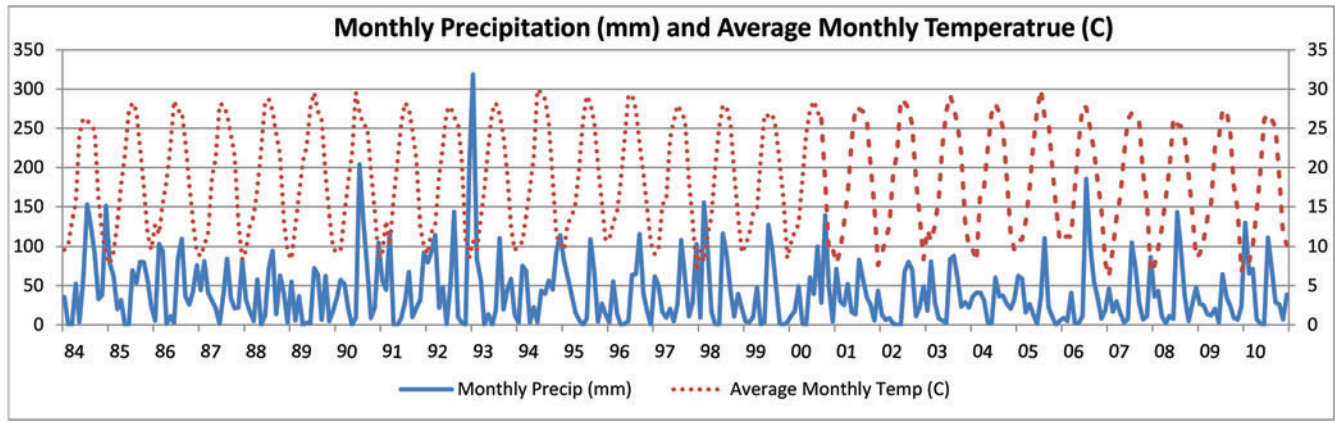


Figure 4—Monthly precipitation (mm) and average monthly temperature (°C) for the Finger Rock Canyon drainage, 1984-2010. (Source: Michael Crimmins based on PRISM [Parameter-elevation Regressions on Independent Slopes Model] climate mapping system data.)

climatic context in which assessments are made and knowledge of expected species variability.

Conceptual Model

A conceptual model of plant responses to climatic conditions is shown in figure 5. It is simplistic in that it does not consider biotic factors such as genetic variability or plant-to-plant interactions. Each of the four solid circles (A-D) represents an assemblage of species that

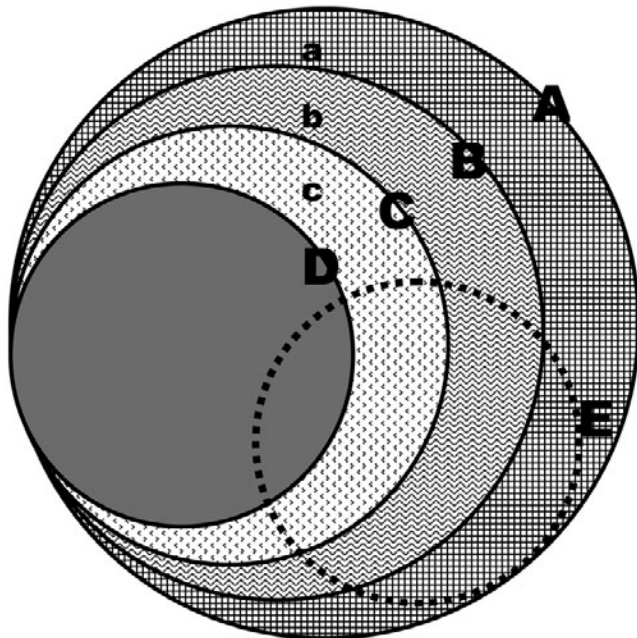


Figure 5—Conceptual Model of Plant Responses to Climate. A = total species in a vegetative association or biotic community. a = seldom seen species. B = species normally reproductive under optimal conditions. b = highly climate sensitive species. C = species normally reproductive under adverse conditions. c = species adapted to adverse conditions. D = species reproductive every year (species most well-adapted to local climatic variability). E = species that should be monitored to detect early ecosystem changes.

include species represented by the circles within them. The number of species in each assemblage will vary not only with vegetative associations but also over time. Different assemblages can be expected for any given year, season, or even month. The relative size of these assemblages, however, is thought to be consistent across association. Most biodiversity is found in the visible portions of the three largest circles, labeled a, b, and c.

Circle A represents the total flora of a vegetative association. Climate variability and climate change may result in highly variable biodiversity as species respond at variable rates (Wather and others 2002). The visible portion of the circle, a, represents species infrequently seen for a variety of reasons, e.g., species requiring highly specific climatic conditions and species at the extreme periphery of their ranges. Peripheral populations are important because they may include distinct traits that facilitate adaptation to climate change (Angert and others 2011; Lesica and Allendorf 1995). In the Finger Rock Canyon drainage, 4% of the taxa have been seen flowering only 1 year and 15% 5 or fewer years.

Circle D includes species that flower every year, i.e., those most well adapted to the local climate regime. These species comprise less than 25% of the total flora in my study area. They are generally common and are frequently the primary focus of monitoring efforts, in my experience. Common species may be the easiest to monitor, but they are common because they are well-adapted to local climatic conditions (Cole 2010). Thus they are least likely to indicate adverse effects of climate change before the system nears or reaches a tipping point.

Climatic variability, specifically the timing and magnitude of temperature and precipitation events, is most apparent in the responses of species represented by circles B and C. The species in these assemblages vary from year to year but are fairly consistent. Circle B includes species that usually reproduce during climatically optimal conditions, as much as 85% of total species. The visible area of the circle, b, represents the most climate-sensitive species. With climate change, it seems highly likely that the first indications of system instability will be seen here and that the most rapid change will occur in this group. Circle C, not more than 60% of the total flora, includes species that are usually reproductive (although populations may be small) during adverse conditions and have a high tolerance to climate variability.

Monitoring for Climate Change

Circle E represents species on which ecosystem monitoring should focus in order to detect instability before it crosses a threshold of no return. Over time, monitoring of a wide range of species can lead not only to a far better understanding of the species in the ecosystem and expected climate variability within species but also to identification of changes occurring in the system in response to climate change. The conceptual model has a number of implications for ecosystem monitoring as it pertains to climate change:

1. Comprehensive flora inventories need to be developed to determine which species need protection and to provide a baseline against which change can be measured. These inventories can be developed during the process of thorough, on-going monitoring.

2. The goal should be to monitor all species. It is not possible to predict accurately which of the species will be most affected by a changing climate because of their individual responses. Monitoring of life forms, which draw moisture from different soil depths is also essential because changes in life form composition can indicate structural instability (House and others 2003; McCluney and others 2011; Schenk and Jackson 2002).

3. Monitoring of ecosystem change needs to occur more than once a year. Different species grow, reproduce, and die at different times of the year. Species flowering in spring may respond to different climatic factors than those flowering in summer (Crimmins and others 2010, 2011). At any point in time a different mix of species will be present. Growth in spring, both above and below the ground, may be important to the reproductive success of species flowering in summer. At a minimum, monitoring should be completed in both spring and summer, preferably in the peak of the growing season. Some climate change models predict a sharp decline in winter precipitation (Karl and others 2009), and this has major ramifications for spring growth and reproduction in arid and semi-arid biomes (Crimmins and others 2008; 2010).

4. More extensive and intensive monitoring during climatically optimal and adverse years can lead to identification of climate sensitive species and better understanding of climate variability at the species level. Past and present monitoring data should be interpreted in terms of “normal,” “optimal,” and “adverse” conditions. We need to look for change and trends.

5. Microhabitats including topographical characteristics such as slope and aspect should be represented in areas monitored because of the biodiversity found in such areas.

Perhaps the greatest limitation on current monitoring practices is inadequate resources—including time, personnel, and knowledge—and a lack of understanding, at the funding level, of the importance of monitoring. It would be ideal to follow Craig’s (2010) first principle to “monitor and study everything all the time,” but this is hardly possible in the “real world” of declining budgets. Even if significantly more funding were available, difficult choices will have to be made as to where and when adequate monitoring is to be done. With a focus on species with known responses to climatic factors, existing monitoring protocols may be useful in detecting long-term change, but a new paradigm is needed if we are to see change before ecosystems reach the point of collapse. There are no easy, simple, or inexpensive answers to the monitoring conundrum because ecosystems are extremely complex and in constant flux.

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Temporal Patterns in Species Flowering in Sky Islands of the Sonoran Desert Ecoregion

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Abstract—Highly variable moisture conditions in the Sonoran Desert play a significant role in shaping the composition and phenology of plants in this water-limited region. The flowering patterns of plants of the Finger Rock trail, located in the Santa Catalina Mountains of southern Arizona, have been very carefully documented on approximately a weekly basis for nearly three decades. These observations, made along a gradient encompassing more than 4,000 ft in elevation, have revealed that flower presence, timing, and duration vary dramatically from year to year for many species in this unique environment.

We developed a daily probability of flowering estimate for each species from the empirical records of presence or absence of flowering and implemented a clustering algorithm to elucidate recurrent temporal flowering patterns among groups of species. Several patterns emerged, and these patterns are consistent with plant functional types. First, across the elevation gradient, over half of all species that have been documented exhibit very low (<10%) probabilities of flowering in any given year, a pattern that exemplifies the high degree of variability and opportunism in this water-limited environment. In addition, there are small groups of species that are consistently seen in flower nearly every year and at nearly the same day of year, regardless of the preceding or concurrent climate conditions. The reliability with which these species in these groups flower, both from year to year and at the same time every year, increases with increasing elevation, and is also higher in summer than in the spring season. Clusters comprised mainly of annual species tended to show lower flowering probabilities and therefore greater variability in flowering; the opposite was generally true for perennial and woody species. The baseline patterns established in this analysis enhance our current understanding of seasonal flowering patterns in this region and serve as a critical step toward understanding how the system may change under future climate conditions.

Introduction

The Sonoran Desert is characterized by two distinct periods of flowering, one in spring and one in summer. However, the assemblage of species seen in flower in a particular season varies widely from year to year (Crimmins and others 2008). Similarly, though the coarse patterns of distinct spring and flowering seasons are consistent from year to year, the timing of species' flowering onset and the length of time individual species remain in flower can vary considerably.

In dry environments, precipitation is the dominant limiting factor, shaping species composition and productivity (Noy-Meir 1973; McClaran and Van Devender 1995) and playing a critical role in cue-

ing phenological events (Beatley 1974; Bowers and Dimmitt 1994; Crimmins and others 2010; Peñuelas and others 2004). However, the relationship between precipitation and plant phenology has generally been established either at a coarse level—for entire plant communities at the seasonal scale (e.g., Crimmins and others 2008)—or for small groups of species (e.g., Aronson and others 1992; Bowers and Dimmitt 1994; Kemp 1983; Kimball and others 2009). Therefore, we can make predictions regarding the flowering response in a given season at a coarse level, such as whether a spring season is likely to be a “good” wildflower year, characterized by abundant and diverse wildflower populations (e.g., Bowers 2005). On the other hand, we mostly lack the ability to make finer-scale predictions such as whether particular species are likely to be seen in flower, when they may initiate flowering, and what the duration of their flowering over the course of the season might be.

Datasets that capture the response of an entire biological community are rare, and repeated measurements of an entire system are even scarcer. Datasets that offer repeated measurements of an entire community are rich and valuable resources that can enhance our empirical understanding of species' responses within the larger ecosystem. In this study, we utilized a long-term record of flowering

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

plant phenology of all species observed (encompassing over 600 taxa on a nearly weekly interval), which enabled us to explore in detail both the year-to-year patterns in flowering for individual species and each species' inter-annual variability in flowering onset and duration.

We use a dataset spanning 27 years to investigate variability and timing of flowering patterns within and spanning the distinct spring and summer seasons characteristic of the Sonoran Desert. Specifically, we asked from year to year, (1) how consistently do individual species flower; (2) how much does flowering onset and duration vary among species; and (3) are there patterns in flowering onset, duration, and inter-annual variability that are relatively consistent across species?

In this study, we evaluated temporal flowering across a 1200-m elevation gradient and explored the consistency of patterns across a moisture gradient encompassing xeric desert scrub to mesic pine forest communities. The findings of this evaluation can guide temporal sampling regimes for long-term monitoring to optimize the likelihood of observing particular species in flower and can also be used to identify peaks in flowering diversity. In addition, these results provide information on resource availability and habitat condition, which is valuable for wildlife species. Finally, this information can also serve as an important baseline from which to begin evaluations of how the system may change under future climate conditions.

Methods

The data examined in this study include 136,036 observations of plants in flower for 601 species made by David Bertelsen. These data are the results of 1,243 round-trip (16 km) hikes of the route to Mt. Kimball, and 25 partial trips of 4.8–12.1 km made over a 27-year period (1984–2010), excluding 2004 and 2005, when the observer was unable to complete regular hikes (4.4 ± 0.01 hikes month⁻¹ [mean \pm SE]). The 8-km hiking route to Mt. Kimball is located on the south slope of the Santa Catalina Mountains, approximately 7 km north of the city limits of Tucson, Arizona, USA, and follows the Finger Rock and Pima Canyon trails. The observer recorded species observed in bloom within approximately 9.1 m of either side of the trail. Observations were recorded along five trail segments approximately 1 mile (1.6 km) in length both on the ascent and descent; on the descent attention was given to verifying records and adding any taxa not already recorded. Trail mile 1 refers to the lowest elevation segment; trail mile 5 refers to the highest elevation; further details regarding the study site and data collection methods are provided in Crimmins and others (2011). Each species was assigned to one of the following functional types: annual/biennial forbs, herbaceous perennials, and woody plants. Functional type groupings were selected based on the different water use strategies employed by plants of semi-arid environments (Burgess 1995; Ehleringer and others 1991).

To evaluate consistency of flowering on each calendar day from year to year, we calculated a "probability of species flowering" (PSF) for each day in the entire record (>9,800 days) for each species. This was done by first interpolating individual species flowering presence/absence observations collected at an irregular interval to a consistent daily matrix of 9,800 days. Changes in the flowering status (presence = 1 or absence = 0) were linearly interpolated between consecutive hikes with a mid-point value of 0.5. All days in the record with a value higher than 0.5 were converted to flowering days (presence = 1) for each species. The full data matrix of daily flowering occurrence was then used to calculate the empirical probability of occurrence for each day of the year. If a species was observed in multiple trail miles, observations specific to each mile were treated independently. The resultant species-mile PSFs provide us with the likelihood of a spe-

cies being observed in flower on each day of the year in a particular trail mile.

Several potential probability of flowering curves could arise from long time-series of phenological status observations. Examples of these and the structure of the input data responsible for these patterns appear in fig. 1. These models represent the extreme cases; we expect most curves would fall somewhere between one or more of these extremes. Individual species PSF plots provide information on several elements: the length of time, or **duration**, that a species is typically seen in flower, the year-to-year **consistency** in the days of year a species is seen in flower, and the **probability** of a species being observed in flower in a given year. The height and width of the peaks result from a combination of these features. Species associated with tall, narrow peaks (fig. 1a) are characterized by a short flowering duration, a high year-to-year consistency, and are seen in flower nearly every year. Species that exhibit a short flowering duration and high consistency but are seen infrequently have narrow, short peaks (fig. 1b). Species that flower in most years for a long duration with high consistency are represented by tall, wide peaks (fig. 1c). These lengthy, short peaks can arise by multiple pathways. First, species that exhibit a long flowering duration with high consistency but flower in few years produce this pattern (fig. 1d). Similarly, short peaks that stretch over a longer period can result from species that flower for short durations and exhibit low consistency, that is, their flowering periods from year to year are highly variable (fig. 1e).

To collapse the individual 1,588 individual species-mile PSF curves into common flowering patterns, individual species' curves were clustered within each mile using a K-means algorithm using Matlab (R2011b). The algorithm uses five iterations of the K-means classifier and retains the clustering with the smallest sum squared error. To assess the optimal number of clusters for the input dataset, an ensemble of clusters ranging from 2 to 20 are generated and then compared using the Davies-Bouldin Index (DBI). A lower DBI indicates greater within-cluster similarity and greater separation between clusters. The smallest number of clusters with the lowest DBI value indicates the simplest efficient grouping of the input data. Seven clusters were retained for each trail mile based on these criteria.

Results

For each of the five trail miles we generated seven clusters (fig. 2), which represent patterns repeated across individual species' PSF plots. We identified 10 cluster patterns (labeled A–J), eight of which were consistent across multiple trail miles (fig. 2). Only cluster I (mile 1) and cluster J (mile 5) were unique to a single mile.

A very clear pattern is represented in cluster A, which is present in each of the five miles. Species associated with this cluster exhibit a very low probability of being seen in flower, and may flower over a very broad range of dates. This cluster encompasses greater than half of the species observed in each of the miles (table 1). The low probabilities associated with species in this cluster result from the comparatively small number of years observed in flower (average 5.7 to 6.9 years) (table 1). Accordingly, cluster A is comprised of many species that flower infrequently and unpredictably. These species may best be represented by model 1b (fig. 1).

Several other patterns were consistent across multiple trail miles. All miles were characterized by at least one spring-flowering cluster (clusters C or F), at least one summer-flowering cluster (clusters D, E, G, or J), and a bimodal flowering cluster (cluster B; fig. 2). Miles 1 and 2 exhibited multiple distinct spring peaks. Miles 2, 3, and 4 also exhibited a mid-year flowering cluster (cluster H), comprised primarily of succulents (table 1). Cluster peaks were generally higher

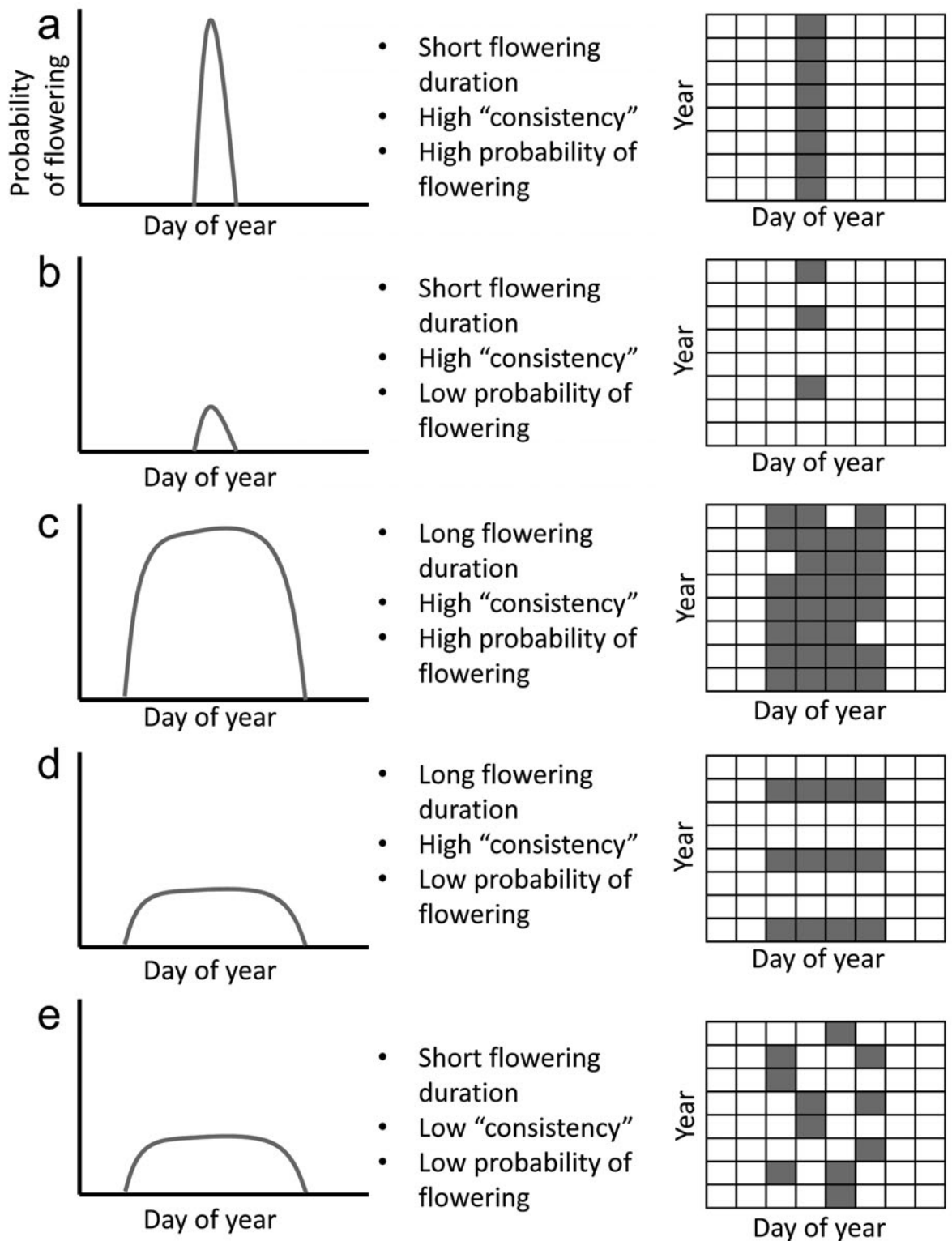


Figure 1—Conceptual model of potential probability of species flowering (PSF) models and the input data structure associated with these models. Potential PSF models appear in the left column; input data matrices appear in the right column. In the input data matrices, cells represent individual days of the year across a series of years. Observations of a species in flower are represented by cells shaded gray; observations of no flower are represented by unshaded cells. (a) a species that flowers in most years, for a short duration and with high consistency in year-to-year timing; (b) a species that flowers infrequently, with a short flowering duration, and with high year-to-year consistency in timing; (c) a species that flowers in most years, with high year-to-year consistency in timing, and for a long duration; (d) a species that flowers infrequently, with high year-to-year consistency in timing, and for a long duration; (e) a species that flowers for a short duration and with low year-to-year consistency in timing.

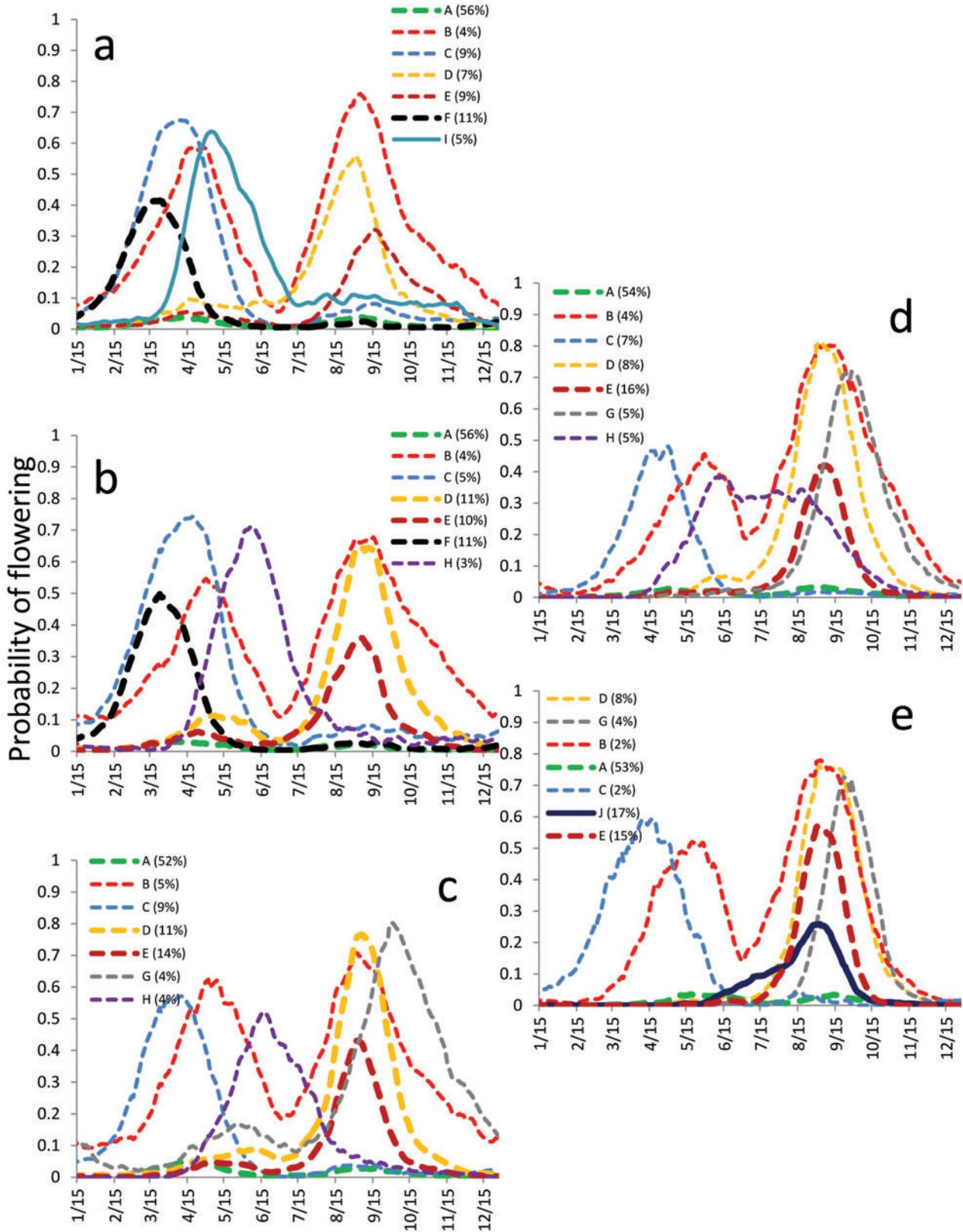


Figure 2—Probability of species occurrence plots for 5 trail miles. (a) mile 1; (b) mile 2; (c) mile 3; (d) mile 4; (e) mile 5. Dashed lines indicate that the cluster is shared between multiple miles; solid lines indicate that cluster is unique to that trail mile. Thicker lines denote clusters that represent ≥10% of species in that mile.

Table 1—Membership of clusters generated from individual species' probability of flowering curves along the route to Mt. Kimball, Santa Catalina Mountains, Arizona, USA.

Cluster	Mile	Cluster membership (count of species)	Cluster membership (% of species in trail mile)	Mean years in flower	St dev years in flower	Annual species	Herbaceous perennial species	Woody species	Succulent species
A	1	205	55.4	6.6	5.5	47%	35%	13%	5%
A	2	202	56.1	5.7	5.6	41%	39%	16%	4%
A	3	185	52.4	6.9	5.9	49%	30%	19%	3%
A	4	159	54.1	6.1	5.7	48%	28%	18%	6%
A	5	112	52.8	6.0	6.0	35%	39%	19%	6%
B	1	15	4.1	26.0	1.5	0%	73%	27%	0%
B	2	13	3.6	26.5	0.8	8%	69%	23%	0%
B	3	17	4.8	26.2	1.7	12%	76%	12%	0%
B	4	12	4.1	26.3	0.9	0%	83%	17%	0%
B	5	5	2.4	26.2	1.1	0%	100%	0%	0%
C	1	32	8.7	24.5	2.2	47%	25%	28%	0%
C	2	18	5.0	25.4	1.8	50%	17%	33%	0%
C	3	33	9.4	22.5	3.3	64%	27%	9%	0%
C	4	22	7.5	20.4	3.8	55%	32%	9%	5%
C	5	4	1.9	24.5	1.0	0%	50%	50%	0%
D	1	26	7.0	22.7	3.2	8%	69%	8%	15%
D	2	41	11.4	24.6	2.9	17%	66%	15%	2%
D	3	39	11.1	25.7	1.4	31%	51%	15%	3%
D	4	23	7.8	25.2	1.9	13%	87%	0%	0%
D	5	16	7.6	25.0	1.9	6%	75%	19%	0%
E	1	34	9.2	18.7	3.7	24%	47%	29%	0%
E	2	36	10.0	21.1	3.6	33%	39%	28%	0%
E	3	51	14.5	20.6	3.9	33%	57%	10%	0%
E	4	48	16.3	18.8	4.0	40%	52%	8%	0%
E	5	31	14.6	20.6	3.7	32%	65%	3%	0%
F	1	41	11.1	18.2	4.1	76%	15%	10%	0%
F	2	41	11.4	20.3	3.7	76%	17%	7%	0%
G	3	13	3.7	24.5	4.5	8%	46%	46%	0%
G	4	16	5.4	24.2	4.3	6%	69%	25%	0%
G	5	9	4.3	25.1	1.5	0%	67%	33%	0%
H	2	9	2.5	25.4	1.1	0%	11%	33%	56%
H	3	15	4.3	23.8	2.9	0%	13%	27%	60%
H	4	14	4.8	23.5	2.9	7%	36%	21%	36%
I	1	17	4.6	23.8	2.9	6%	35%	35%	24%
J	5	35	16.5	16.2	4.4	26%	51%	9%	14%

and narrower in the summer, particularly in the higher elevation miles (4 and 5). Membership of several of the clusters in each mile was quite small (5% or less of the species observed in that mile; fig. 2 and table 1). The distinct flowering patterns exhibited by the species in these clusters are what drive these clusters to exist.

Clusters tended to be dominated by one plant functional type or comprised of a consistent mix of functional types across the elevation gradient (table 1). Cluster B, the bimodal flowering pattern, was comprised of between 73% and 100% herbaceous perennial species (table 1). Cluster C, the spring flowering cluster seen across all 5 miles,

was a mix of annual and perennial species and exhibited a probability of flowering around 60% in miles 1-3; in contrast, the earliest spring flowering cluster exhibited lower probability of flowering, between 40-50% (miles 1 and 2; Cluster F), and was comprised of >75% annual species (table 1). Cluster A, seen in all miles, was a mix of annual and herbaceous perennial species.

For clusters identified in multiple miles, spring cluster peaks generally occurred later at higher miles (fig. 2). The peak for cluster B occurred as a plateau between April 13 and April 27 in mile 1 and peaked around May 19 in mile 5. Summer peaks generally did not

show a lag with increasing elevation. For example, cluster B peaked around September 2 in mile 1 and August 30 in mile 5 in the summer. Similarly, the peak for cluster D was approximately August 30 across all trail miles.

Discussion

The large membership in cluster A characterizes the great variability in which species flower from year to year in the Sonoran Desert and Sky Islands ecosystems; this analysis reveals that greater than half of the species in each trail mile exhibit a smaller than 10% chance of flowering in any given year or on any particular day. The species in this cluster appear to exemplify the opportunistic nature of many desert plants that are known or expected to depend heavily on seasonal moisture and particular antecedent climate conditions to trigger and complete germination, growth, and flowering (Beatley 1974; Bowers 1987; Bowers and Dimmitt 1994; Kemp 1983). This cluster is comprised of a mix of annual plants, herbaceous perennials, and woody species, which employ different strategies for dealing with variable moisture conditions. As the species in this cluster exhibit very low probability of flowering throughout the entire year and from year to year, these species probably represent a wide range of various antecedent and interacting conditions that cue and sustain flowering.

Aside from the dominant pattern of pronounced year-to-year variability captured in cluster A, there are small “core” groups of species that are consistently seen in flower, similar to the model in figure 1a, regardless of the preceding or concurrent climate conditions. The flowering reliability of these “core” groups increases with increasing elevation, and is also higher in summer than in the spring season. The higher probabilities observed in flowering in summer-season species can be explained by these species’ reliance on the summer monsoon to initiate flowering. Compared to winter and spring precipitation, the onset of the summer monsoon is rather regular in this region, and many species’ flowering cues are closely tied to this seasonal rainfall (Crimmins and others 2011).

The results of this analysis demonstrate clear patterns among functional types that are nested within the broad bimodal flowering patterns characteristic of the Sonoran Desert. At lower elevations, the spring season is characterized by multiple overlapping waves of flowering. The first of these waves is characterized primarily by annual species, though the chances of these species flowering are around 50%. At higher elevations, the spring season is characterized by a mix of life forms and a very small number of species flowering.

At low elevations, the probability of species flowering increases as spring progresses, as does the relative proportion of species in flower that are perennial. Similarly, there are patterns within the summer flowering season that vary by functional types composition, though the timing of these peaks exhibits less temporal variability than the spring season.

Our results show a progressively later spring flowering peak with increasing elevation, consistent with studies in high elevation environments, which have demonstrated a lag in the onset of flowering with increasing elevation where temperature is the most influential variable (Rusch 1993; Ziello and others 2009). Indeed, spring flowering of species in this study area has been shown to be heavily influenced by temperature variables (Crimmins and others 2010). In contrast, we did not see a lag in peak flowering dates with increasing elevation in the summer season. This pattern may be a result of the water limitation in this system. Crimmins and others (2011) showed that across this elevation gradient, the onset of summer flowering is driven by the commencement of the summer monsoon rains and that, especially

in dry years, onset of summer flowering occurs rather synchronously across the plant communities occupying the five trail miles.

The results of this study have value for informing long-term monitoring. Recognizing the low probability of flowering for greater than half of the species present in this system in a particular year could significantly benefit monitoring by informing sampling time frames and/or species selection. Further, if monitoring goals necessitate selection of either consistently or infrequently flowering species, this clustering approach could provide guidance.

The findings of this analysis serve to increase our understanding of the seasonal and year-to-year patterns in plant flowering across this elevation gradient, establishing a critical baseline for comparison under future climate conditions. Recent studies in temperate environments have shown varying sensitivity to climate, with earlier-flowering species advancing their flowering dates at a more rapid pace than later-flowering species (Miller-Rushing and Inouye 2009; Sherry and others 2007). Future research in this unique, water-limited system, where species are adapted to high climate variability, should explore whether this pattern can be expected to manifest here as well. Implications of shifts include opening niches for potential invasion by non-native species and de-coupling of trophic interactions.

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Are Madrean Ecosystems Approaching Tipping Points? Anticipating Interactions of Landscape Disturbance and Climate Change

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Abstract—Contemporary climate change is driving transitions in many Madrean ecosystems, but the time scale of these changes is accelerated greatly by severe landscape disturbances such as wildfires and insect outbreaks. Landscape-scale disturbance events such as wildfires interact with prior disturbance patterns and landscape structure to catalyze abrupt transitions to novel ecosystem configurations. These reorganized landscapes are characterized by new disturbance regimes and potentially dramatic departures in species diversity and distributions, community composition, carbon storage, landscape mesoclimate, and soil and hydrologic processes. Post-transition ecosystems can be highly resilient in their altered state, and resistant to return to pre-disturbance conditions in the current and near-term climate regime, possibly representing alternative metastable states. Severe landscape disturbance interacts with, and may be driven by, climate variation to govern ecosystem dynamics and large-scale ecosystem change. We present a conceptual model organized around six key attributes that may drive ecosystems to rapid change and novel trajectories.

Background

Many studies predict changes in species distributions in response to changing climate. At local scales, community composition reflects changes in the suitability of existing habitat for species persistence. Both modeling and empirical studies suggest that such changes due to climate alone are likely to be expressed at multi-annual to decadal time scales (Allen and Breshears 1998, summarized in Parmesan 2006). Recent meta-analyses of range limit studies (Parmesan and Yohe 2003; Chen and others 2011) found that latitudinal and upper elevational limits in the Northern Hemisphere have moved 6.1-16.9 km northward and 6.1-11.0 m upslope per decade. The mechanisms of climate impacts on ecological communities varies, including shifts in species distributions (Gonzalez and others 2010; Rehfeldt 2006), disease (Pounds and others 2005), and phenology (Crimmins and Bertelson 2009).

In contrast, severe large-scale disturbances can reorganize ecosystems on much shorter time scales of days to months (Overpeck and others 1990). High severity fires can cause extensive mortality, alter soils and hillslope geomorphology, and trigger cascading ecosystem changes, especially in vegetation types for which severe fires are atypical (fig. 1). Landscape fires can cause rapid reorganization of ecosystem mass and energy (McKenzie and others 2011), with the consequence that post-fire recovery can extend over years or even decades.

Post-fire ecological transitions have been observed in multiple sites in Southwestern North America. Iniguez (2009) observed evidence of a 19th century type conversion near Rincon Peak in the Rincon Mountains (fig. 2) from ponderosa pine to an evergreen oak community, which appears to have occurred following a high-severity fire in 1867. Savage and Mast (2005) reviewed post-fire recovery trajectories at 10 ponderosa pine sites in the Southwest that experienced crown fires from 1948-1977. Some sites returned to pine dominance, albeit at higher density than previously, while other areas converted to oak shrubfields, chaparral, or non-forested grasslands. Areas burned in the 1,858-ha 1977 Radio Fire on Mt. Elden outside of Flagstaff, Arizona (Passavoy and Fulé 2006), which burned largely in ponderosa pine, remain dominated by shrubs 45 years post-fire. Similar transitions have been observed in the Santa Catalina Mountains following the 2002-2003 Bullock and Aspen fires.

We posit that it is the *combination* of climate change and severe disturbance that is most likely to trigger abrupt ecosystem transitions into novel configurations, rather than either factor acting separately. These new configurations may be resilient in their new state, and resistant to return to pre-disturbance conditions due to synergistic influences of disturbance and climate (Kitzberger and others 2011). In addition to ecological effects, these transitions also include potentially persistent alterations to geomorphic, soil, hydrological, and biogeochemical systems (Scheffer and others 2001). Such abrupt transitions are predicted to become more common under conditions of altered future climate and amplified disturbance regimes (Flannigan and others 2000; Westerling and others 2006; Zinck and others 2011).

Abrupt ecological change is generally defined as a threshold response in key biotic and abiotic ecosystem components (Anderson and others 2008). Such changes may be expressed in shifts in dominant vegetation physiognomy (for example, from forest to shrub communities), species composition, or community structure. Rapid post-disturbance transitions are especially likely if established individuals of dominant

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.



Figure 1—2011 Horseshoe 2 Fire, Chiricahua Mountains.



Figure 2—Remnant southwestern white pine (*Pinus strobiformis*) with multiple fire scars in a netleaf oak (*Q. rugosa*) shrub field originating after stand-replacing fire in 1867, Rincon Peak, Arizona (photo: J.M. Iniguez).

species do not survive a disturbance event. Altered soil, hydrologic, and biogeochemical conditions can reinforce shifts in vegetation types and disturbance regimes, such as a transition from a low-severity forest surface fire regime to a high-severity chaparral shrubland regime (Mayer 2011). Climate provides the envelope within which these

dynamics occur; disturbance provides the trigger for abrupt system reorganization.

Theoretical Foundation

The theoretical basis for understanding type conversion behavior derives from alternative stable state theory. This family of models describes the potential of ecological communities to exist in more than one state over relatively long ecological time. Strictly speaking, these ecological configurations are more properly *metastable* states, i.e., displaying quasi-equilibrium behavior over limited domains of time and under a range of external conditions (e.g., long successional sequences in a given climate). Henceforth, we will refer to *alternative metastable state* (AMS) theory, which provides a framework for ecosystem behavior under both historical and current conditions (Elmqvist and others 2003).

By definition, metastable states maintain a given configuration (e.g., a plant community type) within limited degrees of environmental variation. For example, Madrean ponderosa pine stands or encinal woodlands retain their primary characteristics (species composition, physiognomy, biomass distribution) despite interannual variation in rainfall and temperature, or episodic low-severity fires or insect outbreaks, due to the persistence of established individuals and ongoing reproduction. The community can be displaced or reorganized over long (millennial) time by climate variation, which modifies the envelope of suitability, such as has occurred in the Madrean bioregion throughout the late Pleistocene and Holocene (Holmgren and others 2006; Jackson 2006; Van Devender and others 1984). Transient events—unusually severe fires, droughts, or insect outbreaks—have the potential to trigger rapid community reorganization outside of the envelope of metastability, especially if there is widespread mortality and/or alteration of the biophysical template (Folke and others 2004). Thus transient events, in combination with altered climate, may make rapid ecosystem transitions more likely.

Transitions between metastable states are distinguished from ongoing successional change by the rapidity with which state changes occur. This occurs because the boundaries between metastable states are characterized by positive-feedback interactions that create unstable equilibria. Following a major perturbation, the system reorganizes along one of several possible pathways. One potential outcome is a return to the pre-disruption state, but depending on a variety of factors (see below), the system can instead develop along an alternative trajectory. Positive feedback relationships then tend to reinforce a given trajectory once it has been initiated, because species present in the post-disturbance community provide a source of propagates for ongoing recruitment as well as competitors to other species. These same feedbacks create the emergent property of *resilience* in a given condition once it is established. Unstable equilibria are often asymmetric: a change in one direction is not necessarily equally as likely as a reciprocal change in the other, due to mechanisms that tend to reinforce a given configuration. For example, once dry pine forest has been converted to interior chaparral, the resulting new higher-intensity fire regime may tend to favor resprouting chaparral shrub species, and select against a return to slower-growing arboreal life forms with heat-sensitive canopies; similar dynamics are observed in semi-arid ecosystems invaded by cheatgrass (*Bromus tectorum*), which facilitates fire regimes that exclude previously dominant species.

Post-disturbance pathways are sensitive to initial conditions, which are a primary factor in the assembly rules that govern how communities reorganize (Palmer and others 1997; Temperton and others 2004). For example, the presence of survivors and early post-disturbance colonizers can determine establishment order and thus the capture

of space and resources. This early dominance can be reinforced by growth, reproduction, and competition, resulting in a new metastable state. It is also important to recognize that in some cases, what appear to be alternative metastable states may simply represent slower successional dynamics operating on longer time schedules than ordinarily recognized.

A Framework for Anticipating Threshold Change

We propose a model based on six primary factors that appear to determine post-fire ecosystem trajectories under current and near-term climate in Madrean ecosystems. In this model, the post-disturbance trajectory of an ecosystem is influenced by (1) the type and severity of disturbance, (2) persistence or mortality of dominant species in the pre-disturbance community, (3) alteration of the biophysical template (soils, hydrology, topography), (4) landscape structure that governs multiple spatial ecological processes such as dispersal, (5) the local and regional species pools of available post-disturbance colonizers, and (6) respective life history attributes, especially dispersal, recruitment, and competition, and local and regional climate that determines, among other factors, the availability of suitable conditions for recruitment. Interactions among these mechanisms interact to create the emergent properties often associated with macrosystem behavior, including resistance and resilience. These variables can be used to simulate threshold responses in modeling environments (Keane and others 2011).

Type and Severity of Disturbance—A wide range of ecological and Earth system processes are classified as “disturbance,” including wildfire, insect outbreaks, diseases, floods, hurricanes, tsunamis, landslides, earthquakes, severe droughts and pluvials, freezing events, and numerous others. Some of these (insect outbreaks, disease, and fire) are clearly of biotic origin and can, thus, be considered ecological interactions, which operate at least in part in a density-dependent fashion (i.e., effects are a function of density and size of members of a community). Other disturbances (e.g., floods, hurricanes, tsunamis, landslides, earthquakes, severe droughts and pluvials, and freezing events) are expressions of Earth system processes in which ecological effects tend to be density-independent. Surface and mixed-severity fires in the Madrean ecoregion are keystone ecosystem processes that regulate biomass, nutrient cycling, and community structure in a wide range of community types (Swetnam and others 2001).

The introduction of new species into a community can also introduce novel types of disturbance; for example, the rapid spread of non-native African grasses such as buffelgrass (*Pennisetum ciliare*) into upland communities in the Sonoran Desert has introduced a novel fire regime to which most resident species are poorly adapted (McDonald 2009, Stevens and Falk 2009). As discussed below, these shifts in the fire regime can move an ecosystem into a new self-reinforcing metastable state which is highly resistant to return to the pre-invasion condition.

Mortality and Persistence—Severe disturbances such as wildfires leave relatively few surviving established individuals, opening up niche and physical space for community-level turnover. Indeed, mortality is one of the two primary ways in which severity is indexed; for example, the U.S. Rapid Assessment of Vegetation Condition after Wildfire (RAVG) program (<http://www.fs.fed.us/postfirevegcondition/index.shtml>) uses multi-spectral reflectance criteria to assess post-fire burn severity, by classifying basal area loss by vegetation type (fig. 3). The extent of mortality among the pre-fire community is a key determinant of post-fire trajectories, because established individuals provide communities with physical structure, seed sources, nurse

plant microenvironments, sources of leaf litter, habitat resources for wildlife, *in situ* geochemical pools such as carbon, nitrogen, and other key nutrients, shade, microclimate regulation, and many other functions. The legacy of persisting individuals also represents the initial conditions for community reassembly, and thus, their presence or absence has a major impact on development of the post-disturbance community.

Soil, Hydrologic, and Geomorphic Effects—Low-severity fires appear to have few adverse effects on soils and geomorphology and can contribute to topsoil development through mineralization of nitrogen into plant-available forms, reduction of litter accumulation that makes mineral soil more accessible to seedling roots, and accelerated decomposition of coarse woody debris. In contrast, severe fires can alter soils and hydrology rapidly and substantially through a variety of mechanisms including soil hydrophobicity, volatilization of nitrogen and other key nutrients, loss of soil organic carbon, and loss of litter and duff layers that assist with slope stabilization (Ice and others 2004; Neary and others 2008; fig. 4).

These direct first-order fire effects (i.e., immediate effects that occur as a direct consequence of combustion) are compounded by a wide range of second-order fire effects including reduced water percolation, increased overland water flow, sheet erosion, sediment fluxes into stream channels, debris flows, bank destabilization, accelerated topsoil loss, and hillslope failures (DeBano and others 1998). For example, extensive post-fire debris flows have been documented in the Huachuca and Chiricahua Mountains (Youberg and others, this volume) in the monsoon season following severe fires in 2011. Recovery times for stream channels and riparian communities after severe debris flows can be on the order of decades to centuries.

Where these effects are slight to moderate in severity and extent, many communities will recover after fire to a state similar to the pre-fire condition. However, when soil and hydrogeomorphic impacts are severe and widespread, an immediate return to the pre-fire condition may be precluded because the biophysical template is no longer suitable. Extensive soil loss also eliminates the soil seed bank, which is a key component of post-disturbance biotic recovery. Hart and others (2005) found that severe fires can also alter the soil microbial communities (both fungal and bacterial) through extensive belowground mortality. These changes can be linked to shifts in plant community composition and changes in key ecosystem processes such as C sequestration, nutrient fluxes, soil physical structure, and plant-microbe mutualisms.

Landscape Structure and Dispersal Processes—The spatial properties of post-fire environments are important determinants of post-fire trajectories. Large fires characteristically leave a legacy of complex landscape mosaics of burn severity across vegetation types. Roughly 4 to 35% of the area within the perimeters of large recent fires in the western United States is classified as high burn severity using delta Normalized Burn Ratio (dNBR), and Normalized Difference Vegetation Index (NDVI) indices (www.mtbs.gov). Moderate severity typically accounts for 20 to 45%, and low severity or unburned areas 33 to 61% (Kotliar and others 2003; Lentile and others 2007). Less is known about the severity patch structure of historical fire regimes, although tree-ring studies in high fire frequency systems such as ponderosa and Jeffrey pine (*P. jeffreyi*) forests indicate that the extent of high-severity effects was generally limited (Swetnam and others 2001; Falk and others 2011). At higher elevations, however, patches were generally larger contiguous areas of high severity in wet mixed-conifer and spruce-fir forests (Margolis and others 2007).

In addition to the proportion of the landscape in each severity class, the size of contiguous patches is an important landscape variable

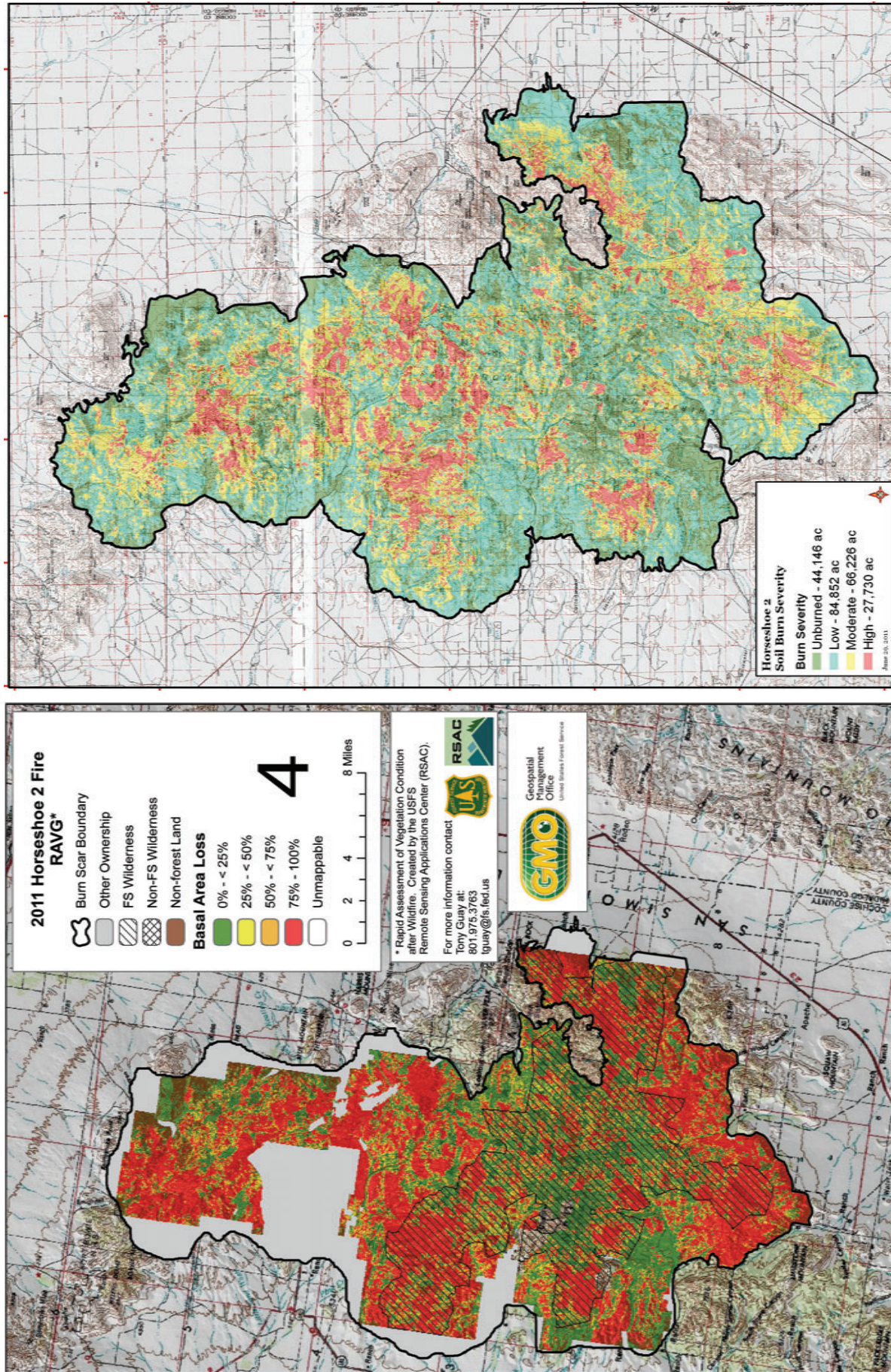


Figure 3—Burn severity images from 2011 Horseshoe 2 fire, Chiricahua Mountains, Arizona. Left: Vegetation burn severity, Rapid Assessment of Vegetation Condition after Wildfire (RAVG), USFS Remote Sensing Applications Center (RSAC, (<http://www.fs.fed.us/postfirevegcondition/index.shtml>)). Right: soil burn severity, accessed through Monitoring Trends in Burn Severity (MTBS, www.mtbs.gov).

(Haire and McGarigal 2010). In contrast to historical fire regimes, contemporary fires often create large patches of high-severity fire effects in the order of 1,000-10,000 ha in size in what were formerly low-severity/high-frequency systems such as ponderosa pine and dry mixed conifer forests where such patches are believed to have been historically of 10-100 ha (fig. 5). The resulting altered landscape structure such as anomalously large high-severity patches following extreme disturbance events may restrict seed dispersal of previously dominant species while favoring other species with rapid long-range dispersal. For example, Bonnet and others (2005) found that most post-fire seed dispersal following a high-severity fire in a South Dakota ponderosa pine forest was restricted to approximately 150 m from seed sources on the edge of residual forest. By this measure, the centers of high severity patches larger than 10 ha with a minimum lateral dimension of ≥ 300 m would require multiple generations for propagules to reach the interior by natural dispersal processes. Species with longer-range dispersal or with persisting vegetative potential (e.g., sprouting species) would have a significant advantage in capturing post-fire occupancy (Haire and McGarigal 2010).

Local and Regional Species Pools—The pool of species available to recolonize a site following disturbance is a key determinant of post-fire ecological trajectories (Menninger and Palmer 2006). Even when suitable biophysical conditions exist for establishment, species must be present and be able to reproduce to become part of the developing community. Clearly, species that can persist through disturbance have a significant advantage over others that must disperse to the site. Persistence is, in turn, a function of evolved life history attributes that reflect a range of evolutionary responses to disturbance (Bond and van Wilgen 1996). For example, the thick bark and lifted crowns characteristic of ponderosa and Jeffrey pines are widely understood as adaptations to surviving low-intensity fires burning in surface fuels, in which survivorship of mature individuals is maximized (Keeley and Zedler 1998). Other species including Chihuahua pine (*P. leiophylla*) and many Madrean oaks (*Quercus* spp.) can resprout after being top-killed, providing a persistence mechanism that may facilitate rapid post-fire occupancy (fig. 6). Aspen (*Populus tremuloides*) clones similarly employ a vegetative life history strategy for post-fire response, although both oaks and aspen also reproduce sexually. These reproductive strategies allow these native species to capture post-fire

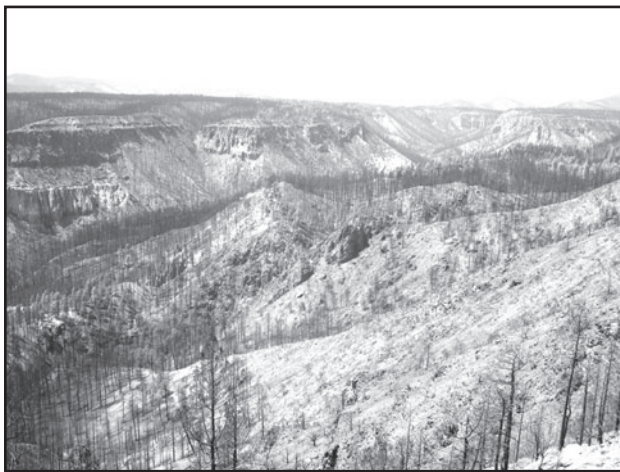


Figure 4—High soil and vegetation burn severity on steep slopes of Cochiti Canyon, 2011 Las Conchas fire, Jemez Mountains, New Mexico.



Figure 5—Large high-severity burn patch, 2011 Horseshoe 2 fire, Chiricahua Mountains, Arizona.

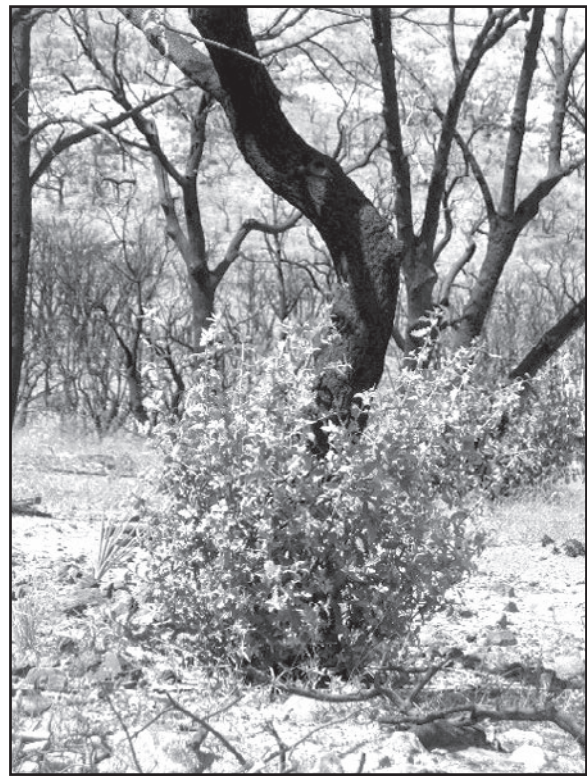


Figure 6—Rapid resprouting of oaks following 2011 Monument Fire, Huachuca Mountains, Arizona.

environments quickly and to persist once established. For example, Gambel oak (*Q. gambellii*) was observed resprouting within weeks of both the 2000 Cerro Grande Fire and the 2011 Las Conchas Fire in the Jemez Mountains, New Mexico. These evolutionary adaptations to post-fire colonization suggests that type conversions (e.g., from pine-dominated forest to oak-dominated scrub), however long they may persist, are part of the historical post-fire behavior of Madrean ecosystems. However, other factors (such as climate and landscape

change) may render these conversions permanent, or at least more persistent than in pre-settlement environments.

By contrast, in upper Sonoran Desert communities in the Madrean bioregion, the primary agents of abrupt and radical change in the native fire regime are invasive non-native grasses. These changes are among the clearest expressions of tipping point behavior in Madrean ecosystems. Natural Sonoran Desert vegetation provides very low fine fuel mass and connectivity due to the dominance of intermingling woody vegetation for much of the year and wide spacing of established plants. Under these conditions, ignitions rarely generate a spreading fire due to the lack of sufficient spatially-continuous fine fuels to sustain a chain reaction. As a result, fires in the Sonoran Desert are rare and low intensity (heat per unit area-time). Consequently, most species of the community lack adaptations to survive fire.

Introduced African grasses, particularly buffelgrass, have changed the fuel environment in Sonoran communities by infilling interspaces with increased, spatially continuous fine fuels (fig. 7). In addition, the foliage of buffelgrass is persistent for many months after curing, increasing the flammability of the fuel bed for the driest months of the year. Buffelgrass is fire tolerant, a formidable belowground competitor (Olsson and others 2011; Stevens and Falk 2009), and can rapidly assume dominance in the herbaceous community. The net result is that areas that have been invaded by buffelgrass become converted to a novel community type with high herbaceous fuel loads of up to 600-1,200 g/m², two orders of magnitude more than un-invaded desert (McDonald 2009) and frequent high-intensity fires that are lethal to many native desert species. Columnar cacti such as saguaro (*Carnegiea gigantea*) are particularly susceptible due to their thin epidermis that is easily damaged by levels of heat typically generated in a wildfire. Once the “grass-fire cycle” is established, the community is resilient in its new configuration and resistant to return to the pre-invasion state (Brooks 2008).

Climate Change—The “bioclimatic envelope” is a central determinant of species distributions and climate variables are key dimensions in a species’ niche space. Niches are non-spatial combinations of multiple variables that define the conditions under which a species can maintain a non-negative population growth rate (λ). The niche is the product of species evolution, including phenotypic plasticity; where $\lambda \geq 1$, a population is self-sustaining (Colwell and Rangel



Figure 7—Prescribed experimental burn in buffelgrass stand, Altar Valley, Arizona (photo: C. J. McDonald).

2009). When the hyperdimensional niche volume is mapped onto geographic space, the result is the total potential spatial distribution of a species in the absence of competition or other limiting factors. Regional climate along with soils, topography, and hydrology also provides the context for the distribution of biotic communities.

Although climate-species and climate-community relationships are mechanistic, they are not deterministic; many more community configurations are possible within a given climate envelope at a given location and few species occupy their entire potential geographic range. In niche theory, the *realized niche* is the portion of the total *fundamental niche* hypervolume that a species occupies. Realized niche space is narrower than the fundamental niche for any given axis due to competition, dispersal limitations, and other factors. The geographic expression of the realized niche is the potential habitat of a species. Similar relationships hold for the distribution of biotic communities as assemblages of multiple interacting species. These non-deterministic relationships are the foundation for the potential for alternative metastable states.

Bioclimatic envelope (BCE) models are used widely to generate null hypotheses for potential species responses to climate change. In a BCE framework, changing climate conditions require a species to follow one of two possible pathways (Colwell and Rangel 2009). One alternative is that the species retains its current niche requirements. In this case, the species must move geographically to remain within its potential habitat zone of suitable climate. In an era of increasing global and regional temperatures, this is usually interpreted as pressure to move upslope or poleward. Thus, in this potential adaptive response, niche space is retained, and adaptation occurs by movement in geographic space. The second alternative is the converse; the species adapts its niche requirements *in situ* to new conditions but retains its current geographic distribution; in other words, the species evolves. Many species contain alleles, present in the population at low frequency, that may provide the basis for adaptation to novel conditions (e.g., tolerance of higher temperatures or drought). As climate changes, these alleles may increase in their frequency and the species’ niche space is altered to fit current conditions. Most species also retain some phenotypic plasticity, which retains fitness under variable conditions within the current genotypes and may facilitate local adaptive responses.

Climate variability and secular (anthropogenic) trend provide the envelope in which threshold responses may occur (Alley and others 2003; McNeall and others 2011). Species distributions represent current geographic range in most BCE modeling, and thus implicitly, the climate tolerance of established individuals. However, the niche space for recruitment—the “regeneration niche”—is not only smaller than the niche space for established individuals but occupies the cooler, wetter domain of the niche (fig. 8). Established individuals of a species such as ponderosa pine or Douglas-fir (*Pseudotsuga menziesii*) can persist through dry years and even sustained periods of drought and high temperatures, but these same conditions are lethal for recently germinated seedlings. Thus, a projected warmer and drier climate in the Madrean ecoregion may not allow for post-fire regeneration of previously dominant species, especially if there is high disturbance-related mortality.

In addition to regulating species distributions and post-fire regeneration, altered climate also increases the probability of severe fires (Flannigan and others 2000). Fire initiation and spread are facilitated by warmer, drier, windier conditions that reduce fuel moistures and promote the combustion chain reaction (Pyne and others 1996). Fire severity may also increase under these climatic conditions, due to decreased live fuel moistures and the resulting increased flammability of vegetation. Finally, the length of fire season is projected to increase

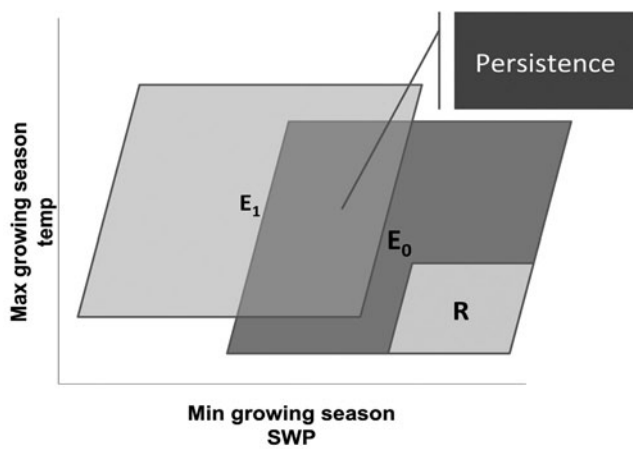


Figure 8—The climate state space in which established individuals can persist (E_0), illustrated here on axes of minimum growing season soil water potential (SWP) and maximum growing season temperature. Most climate projections for the Madrean bioregion indicate generally warmer and drier conditions (E_1). Established individuals can persist in the intersection of these two spaces. However, climate requirements for seedling recruitment (R) are in the cooler, wetter domain of the climate space, which no longer intersects climate regime E_1 .

with changing climate and seasonality, as reflected in the increased number of days with energy release component (ERC) greater than critical values (Brown and others 2004). Thus, altered climate may play an additional destabilizing role in Madrean ecosystems by direct alteration of fire regimes.

As Flannigan and others (2000) observe, “The almost instantaneous response of the fire regime to changes in climate has the potential to overshadow importance of direct effects of global warming on species distribution, migration, substitution and extinction...[F]ire is a catalyst for vegetation change.” The collective effect of disturbance-climate interactions is to rapidly and persistently change landscape patterns and processes including disturbance regimes, vegetation composition, carbon dynamics, and hydrologic balance (Breshears and others 2005; O’Connor and others 2011). The central challenge confronting ecosystem scientists and managers is to understand how fire behavior and legacies of prior disturbance may interact with climate variability to influence post-fire recruitment and ecosystem trajectories, and how these transitions can be managed to maintain sustainable ecosystems.

Broader Impacts

The potential for abrupt ecological and hydrologic change in response to climate and disturbance is of central importance to ecosystem management in a changing world. As climate change progresses, species assemblages and ecosystem disturbance regimes are already changing in ways that challenge the foundations of ecosystem management, especially in arid and semi-arid regions (Allen and Breshears 1998; Aronson and others 1993; Breshears and others 2005; Quijada-Mascareñas and others, in press). Major fires, insect outbreaks, forest dieback, and other phenomena are already creating new and serious stressors to terrestrial ecosystems (Overpeck and others 1990). Moreover, the character, function, and integrity of ecosystems are fundamental to human society in innumerable ways. Thus, if ecosystems begin to change abruptly and profoundly, the

impacts are likely to ripple through human society as well as the biosphere itself.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Preliminary Assessment of Changes in a Lizard Assemblage at an Ecotone in Southeastern Arizona

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Abstract—The Madrean Archipelago and its associated valleys have the highest diversity of lizards in the United States. This is due to a convergence of ecoregions in an area that provides excellent environmental conditions for life history needs of terrestrial ectotherms. The study area, near Safford, Arizona, is known to have about 20 species of sympatric lizards, although only about one-half are common. The lizard community is represented by species of the Sonoran and Chihuahuan deserts, semi-desert grasslands, and lower Madrean and boreal woodlands. It has recently been suggested that lizard species are expected to decline globally due to climate change and other reasons. A study site representing an ecotone between desert and grassland/montane/riparian vegetation types in a foothills situation was chosen, as ecotones are marginal habitats that are expected to be sensitive to environmental change. Study objectives were to assess the baseline lizard community and detect changes in the lizard assemblage over time due to climate change and other factors. During systematic road transects, a total of 3,889 lizards representing 13 species were recorded during 60 visits in 2003 ($n = 8$ visits), 2010 ($n = 12$), and 2011 ($n = 40$). Although this represents the early stages of a long-term monitoring program, preliminary observations show differences in the lizard assemblage between years consistent with climate change predictions.

Introduction

The Madrean Archipelago's "sky island" mountain ranges and valleys have the highest diversity of lizards in the United States of America; nearly one-third of all U.S. species (about 37-39/120) are found in southeastern Arizona and adjacent New Mexico (Jones and Lovich 2009). There can be about 15-20 sympatric species in a small area, where the mountains meet the valleys (Degenhardt and others, 1996 [p. 208]; Jones 2009; Lazaroff and others, 2006).

Literature suggests lizards are declining for a variety of reasons including habitat loss, invasive species, and competition with other species (Gibbons and others, 2000; Olson 2012). Sinervo and others (2010) documented local extinctions of lizards from study plots in Mexico, making a cause-and-effects case for the decline in diversity due to climate change. They went on to describe how the life history attributes of lizards are such that increased spring temperatures and other factors made lizards, as a group, susceptible to extirpation and extinction. They predicted that by 2080 about 40% of lizard species would become locally extinct and 20% would become globally extinct.

When the Sinervo and others (2010) paper was published, I reinitiated surveys from 2003 (Jones 2009) to identify potential changes in the local lizard assemblage since that time, as well as qualitative changes since the Nickerson and Mays (1969) inventory of the Pinaleno

Mountains. In this paper I document some changes in the lizard assemblage, although surveys to date are only the beginning of what is intended to be a long-term monitoring project. Thus, results reported here are preliminary or observational, but do help establish a baseline of distribution and relative abundance of commonly encountered species, as well as highlighting some inter-year trends.

Study Area

The study area is about 10 mi S of Safford, Graham County, Arizona, along a 2.7-mi stretch of road (Forest Road 57) from its junction with Swift Trail (Highway 366). This dirt road is usually termed Marijilda Road, because it accesses Marijilda Creek. Elevation ranges from about 3,810 to 4,010 ft above mean sea level. Adjacent vegetation is primarily semi-desert grassland, but the area is situated at an ecotone between two deserts (Sonoran and Chihuahuan) in the San Simon Valley and semi-desert grasslands and Madrean encinal (oak) woodlands in the foothills of the Pinaleno Mountains (Brown 1994). Vegetation is primarily composed of grasses, shrubs, cacti, and small trees. Lehmann Lovegrass (*Eragrostis lehmanniana*, a non-native bunchgrass), Velvet Mesquite (*Prosopis velutina*), Engelmann Prickly Pear (*Opuntia engelmannii*), and Soapstone Yucca (*Yucca elata*) are among the common plant species, but desert scrub, riparian, and encinal woodland species are also present (Jones 2009, unpublished data). Because the area is rocky, sections of the shoulders of Marijilda Road are replete with boulders and boulder piles, partially an artifact of road construction. The first 0.4 miles of road approach the foothills from the desert valley, then the road turns to parallel the lower slopes of the mountains. The transect ends at Marijilda Creek, a perennial stream with deciduous riparian vegetation.

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Methods

In 2003, 2010, and 2011, I conducted a road-transect tally of lizards along Marijilda Road, according to a protocol; the method is discussed in greater detail elsewhere (Jones 2009). Basically, the observer drove very slowly along Marijilda Road, and stopped when a lizard was seen. The lizard was then viewed through binoculars and identified to species and age class (hatchling, juvenile, subadult, adult), and the 0.1 mi segment of road was recorded. Only the driver tallied lizards seen; passengers (if present) were not allowed to point out lizards. Lizards in the Desert Spiny Lizard complex (*Sceloporus magister* and *S. bimaculosus*) were recorded simply as “*Sceloporus magister* complex” because both species are sometimes difficult to distinguish and likely hybridize in the area (Jones and Schwalbe 2009; Phelan and Brattstrom 1955). Lizards of the *Aspidoscelis sonorae* complex are recorded as *A. flagellicauda*. Without genetic confirmation, I consider *A. flagellicauda* to be the only species in the *A. sonorae* complex present, although HerpNet (an online resource of museum records) reports *A. sonorae*, *A. flagellicauda*, and *A. exsanguis* from the immediate vicinity. All species in the complex are similar and there are taxonomic uncertainties (Jones and Lovich 2009).

Starting in June 2010, surveys were conducted year-round. There was a minimum of one survey per month during November through February, and one survey per week March through October. Surveys

were conducted when temperature, sunlight, wind, and cloud cover were conducive to surface activity of lizards (temperatures between 75 and 95 °F, with mid-80’s being optimal, plus low wind and low cloud cover). Starting time was as early as 0700 in the summer and as late as 1400 in the winter.

Age class data were recorded differently between 2010 and 2011 (not at all in 2003), and there was apparent observer bias in 2011. In order to compare results of reproductive output between 2010 and 2011, I limited observations to my own and transformed age class codes to make them comparable. Age classes reported here are classified as Young (= hatchlings and young-of-year juveniles) or Adult (= subadult or adult). The distinction is based on species-specific phenotypic attributes (e.g., size, coloration, pattern, and secondary sexual characters) and the appearance of young-of-year.

Results

Jones (2009) reported that 19 species have been documented along the Marijilda Road and adjacent lower Swift Trail, but presently I consider the total to be 20 (table 1), counting both species of the *Sceloporus magister* complex. *Elgaria kingii* is a cryptic species that may be present in the riparian area, but has not been detected from Marijilda Creek, although it has been documented from nearby Noon Creek (Nickerson and Mays 1969). Interestingly, *Holbrookia*

Table 1—Lizards of Marijilda study site and adjacent lower Swift Trail. Detections (counts) are for all systematic road-transect surveys in 2003, 2010, and 2011. Species not detected during surveys were opportunistic or had been documented in the literature. *Sceloporus magister* complex includes *S. magister*, *S. bimaculosus*, and presumptive hybrids. See Jones and Lovich (2009) for a discussion of taxonomy and nomenclature, which is recognized here.

Standard English Name	Scientific Name	Code	Count	Percent
Ornate Tree Lizard	<i>Urosaurus ornatus</i>	UROR	1560	40
Common Side-blotched Lizard	<i>Uta stansburiana</i>	UTST	809	21
Desert Spiny Lizard complex	<i>Sceloporus magister</i> complex	SCMC	611	16
Tiger Whiptail	<i>Aspidoscelis tigris</i>	ASTI	277	7
Eastern Collared Lizard	<i>Crotaphytus collaris</i>	CRCO	191	5
Greater Earless Lizard	<i>Cophosaurus texanus</i>	COTE	187	5
Clark’s Spiny Lizard	<i>S. clarkii</i>	SCCL	94	2
Desert Grassland Whiptail	<i>A. uniparens</i>	ASUN	37	1
Regal Horned Lizard	<i>Phrynosoma solare</i>	PHSO	6	<1
Round-tailed Horned Lizard	<i>P. modestum</i>	PHMO	3	<1
Long-nosed Leopard Lizard	<i>Gambelia wislizenii</i>	GAWI	2	<1
Gila Spotted Whiptail	<i>A. flagellicauda</i>	ASFL	2	<1
Zebra-tailed Lizard	<i>Callisaurus draconoides</i>	CADR	1	<1
Hybrid horned lizard	<i>P. solare</i> × <i>P. modestum</i>	PHHY	1	<1
Unidentified lizards		UNKN	108	3
Western Banded Gecko	<i>Coleonyx variegatus</i>	COVA	0	0
Gila Monster	<i>Heloderma suspectum</i>	HESU	0	0
Texas Horned Lizard	<i>P. cornutum</i>	PHCO	0	0
Greater Short-horned Lizard	<i>P. hernandesi</i>	PHHE	0	0
Great Plains Skink	<i>Plestiodon obsoletus</i>	PLOB	0	0
Yarrow’s Spiny Lizard	<i>S. jarrovii</i>	SCJA	0	0
Total	20 species		3,889	100

maculata and *Sceloporus undulatus* complex seem to be absent, but they have been documented from the vicinity (Nickerson and Mays 1969).

A total of 60 surveys were completed: 8 in 2003 (1 June to 3 August), 12 in 2010 (26 June to 11 December), and 40 in 2011 (all months). The only complete calendar-year survey was 2011 because that was the first complete year when long-term monitoring was an objective. There were a total of 3,889 lizard detections (range 0 - 179 detections per visit, mean = 64.8 sd = 38.2) during the 3 survey years. Thirteen species were recorded during road tallies (table 1). The most commonly detected species (at least 5% of detections) were Ornate Tree Lizard (*Urosaurus ornatus*), Common Side-blotched Lizard (*Uta stansburiana*), Desert Spiny Lizard complex, Tiger Whiptail (*Aspidoscelis tigris*), Eastern Collared Lizard (*Crotaphytus collaris*), and Greater Earless Lizard (*Cophosaurus texanus*). Species not detected during transects were assumed to be rare in the study area, nocturnal, or cryptic. Some species, such as *U. ornatus*, *U. stansburiana*, and parthenogenetic whiptails are known to frequent disturbed areas, such as the road margin (Jones and Lovich 2009; Wright and Lowe 1968).

Lizards were detected year-round, in a generally bimodal distribution reflecting spring and summer (monsoonal) peaks of activity (fig. 1). In 2011 (the complete year), seasonal activity varied by species. Only *U. stansburiana* (especially) and *U. ornatus* were active during the winter, and only then on warm days (generally in the 60's). *Sceloporus clarkii* (n = 58) also had a long period of activity (March through November). *Aspidoscelis uniparens* (n = 26) had the narrowest peak of activity, with 65% of the detections in July, immediately following the onset of summer rains. *Aspidoscelis tigris* was only active during hot periods, with 88% (n = 203) being active June through August. The other species showed a generally normal curve from spring through fall, although there was a profound increase in surface activity for some species with the onset of summer rains. This spike was apparent for *A. uniparens*, *U. ornatus*, *U. stansburiana*, and *S. magister* complex. Horned lizards (*Phrynosoma solare*, *P. modestum*, and a hybrid [Jones and Winsor, in press]) also were mostly detected after the onset of the monsoon (71% [5/7] detections). Although sample size was low for horned lizards, monsoonal peak activity was noted in other years and from opportunistic observations on the adjacent

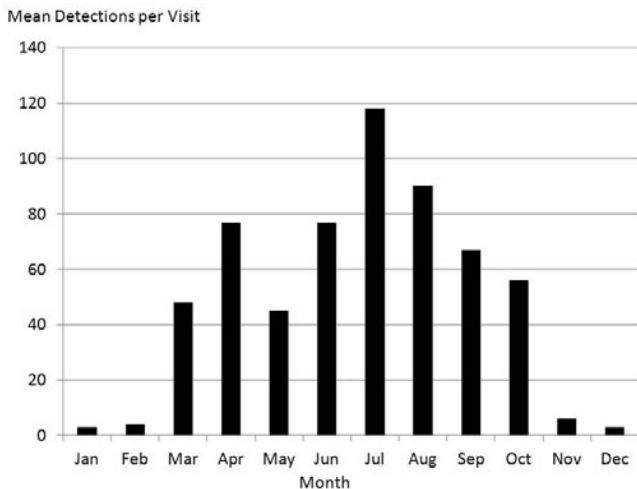


Figure 1—Mean detections of lizards (Y-axis) by month in 2011, showing the bimodal pattern of spring and monsoon peaks of surface activity. In 2010, there was another peak in late summer and early fall due to the emergence of young-of-year.

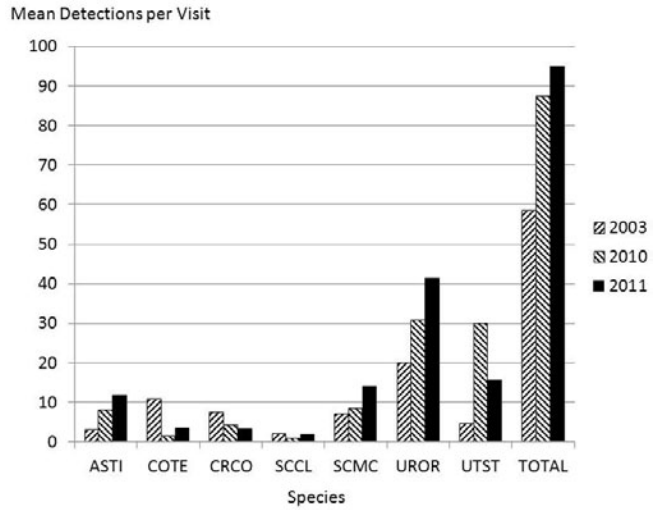


Figure 2—Mean detections per visit of common species by year for June through August, the only months surveyed in all 3 years. Species codes are shown in Table 1.

paved Swift Trail. There was no apparent monsoonal spike for *A. tigris*, *C. collaris*, or *C. texanus*.

A comparison of differences between years had to be limited to June, July, and August, the only months that were sampled in all 3 years. Figure 2 shows the differences in the relative detections of common species. There were observed decreases over time (2003 vs. 2010/2011) in *C. texanus* and *C. collaris* and an increase in *A. tigris* and *U. stansburiana*. In fact, *U. stansburiana* was considered extremely rare on Marijilda road in the 1960's despite extensive searches for it (Nickerson and Mays 1969), but it is now extremely abundant.

Figure 3 shows differences in age-class distribution for common species between 2010 and 2011. The data clearly show a higher proportion of Young to Adult categories in 2010 than 2011, with the exception of *U. stansburiana*. This observation is consistent with the expectations from the winter drought pattern between years (e.g., Vitt and others, 1978).

One of the ways I tracked changes in the lizard assemblage was by comparing distribution of detections by species along the transect. Overall, the first mile or so of the transect had the highest detection rate and presumably the highest density of surface-active lizards (fig. 4). This pattern was similar in all years. The detection rate dropped with increasing distance from the start, although there was an increase in detections at the end of the road, which corresponds to the Marijilda Creek riparian area. Most of the species were not evenly distributed. The large number of detections in the first part of the transect was primarily due to the three most common species, *U. ornatus*, *U. stansburiana*, and *S. magister* complex. *Urosaurus ornatus*, *C. texanus*, and *S. clarkii* were responsible for most observations at the creek. *Aspidoscelis tigris* (2003-2011) and *C. texanus* (2003 only, fig. 5) were fairly evenly distributed along the transect. *Crotaphytus collaris* and *A. uniparens*, were most abundant in the upper one-half of the transect. *Sceloporus clarkii* was usually found in distinct segments. According to data, *C. texanus* was much more abundant in 2003, but it is interesting to note that the distribution along the transect also changed. In 2003, the species was common and widely distributed, while in 2010 and 2011, there were far fewer detections and the species was mostly detected in two or three distinct road segments (fig. 5).

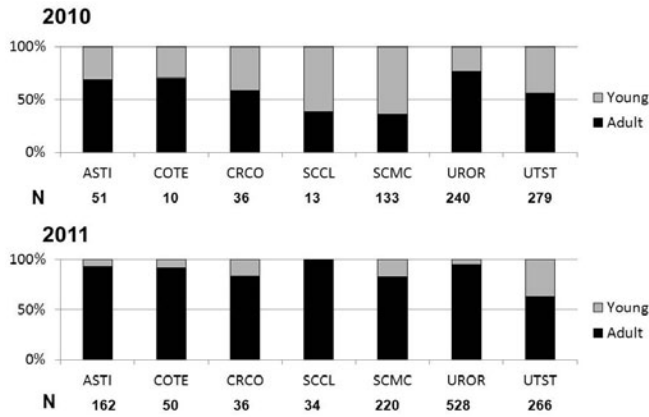


Figure 3—A coarse comparison of relative reproductive output between 2010 and 2011 (see text for explanation), June through October. There was good winter precipitation in 2009-2010, which translated to a good year for annuals and flowering perennials (hence, abundant insect prey), whereas 2010-2011 was a dry winter with few annuals (hence, reduced insect prey). Decreases in reproductive output due to frequent winter drought years could result in population declines and possibly extirpation for some species. However, the role of monsoonal moisture and reproductive success is poorly understood. Species codes are shown in Table 1.

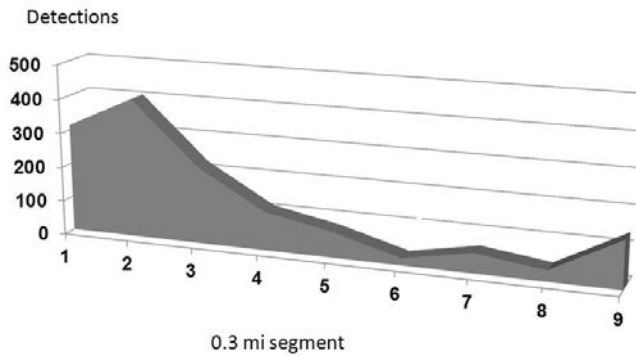


Figure 4—Total detections of all species of lizards by road segments for a 1-year subset in 2010-2011 (n = 1,380 detections). Lizards are recorded by 0.1-mi segments, but are combined here in 0.3-mi segments for display. Segment 6 (mile 1.3-1.6) is the area treated for invasive weeds, but notice that lizards are not particularly abundant in either side of the area.

Discussion

This study is attempting to answer three major questions: (1) which lizard species compose the assemblage, (2) how they are distributed spatially and temporally, and (3) how the assemblage will change over time. The third part requires a cause-and-effect explanation, especially as it relates to climate change.

For the first question, I reviewed the literature and HerpNet, conducted surveys, and spent many opportunistic hours in the study area between 2003 and 2011. The lizard assemblage should be accurate now, although other rare or cryptic species could be detected in the future. Jones (2009) reported that the study area has the highest diversity of lizard species (for such a small area) documented anywhere in the United States. Other areas of southeastern Arizona or adjacent New

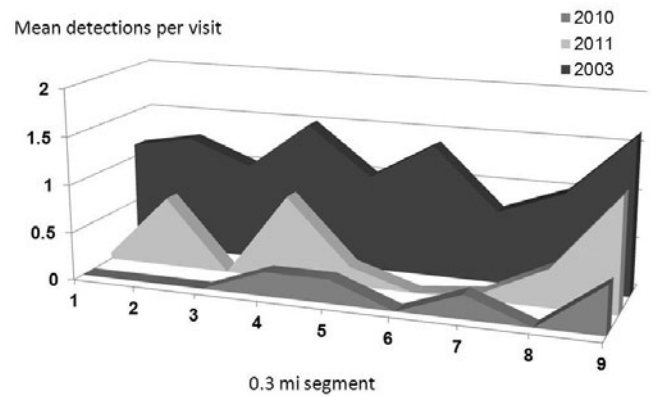


Figure 5—Mean detections of *Cophosaurus texanus* by 0.3-mi segment by year. In 2003 this species was the second most abundant species (18.4% of detections) and was widespread across the study area. In 2010 and 2011 there were considerably fewer observations (1.2% and 3.2%, respectively) and the lizards were in discrete areas (usually near washes and Marijilda Creek riparian area).

Mexico likely have a similar level of diversity, but clearly the Madrean Archipelago and surrounding valleys have the highest diversity in the country. The explanation for the high diversity was reported by Jones (2009): the area is a convergence zone of physiographic provinces that each has a high diversity of lizard species.

The second question—how lizards are distributed along the transect—is starting to unfold. Distribution of most species is not random and patterns are emerging. I am currently engaged in an intensive habitat characterization study component along the transect to determine why lizards are distributed as they are. Observations suggest certain variables will likely help explain abundance, such as distribution and type of rock, vegetation community, topography, and topographic features (e.g., desert approach, foothill, stream). Another observation is that the segment of road from about milepost 1.3-1.6 has the least number of detections, despite having the best visibility of the entire transect. This area was treated for invasive weeds and regrowth is sparse. However, treatment of invasive weeds in a small area to abate spread may be a very important conservation measure that is best evaluated at a larger scale.

The third question is the crux of the study. The Sinervo and others (2010) prediction of large-scale lizard declines was the impetus to re-initiate surveys. Marijilda was selected because of the high diversity and apparent high abundance of lizards, and its setting in an ecotone. Because ecotones are at the edge of vegetation communities, they are expected to have sensitivity to show change from altered climate patterns or other factors (Allen and Breshears 1998, Loehle 2000, Noble 1993). Unfortunately, when the study was initiated in 2003, that was not a goal, so the 2003 data are limited, and the Nickerson and Mays (1969) paper was qualitative. However, these provide the only information we have on the area before 2010. The observations from then to now are generally consistent with climate change predictions. *Cophosaurus texanus*, a foothill species in the Marijilda area, has gone from being extremely abundant and widespread to uncommon with a disjunct distribution. *Uta stansburiana*, a desert species, has gone from being “extremely rare” (Nickerson and Mays 1969) to extremely abundant.

It is well established in the literature that lizard populations are known to be naturally dynamic between years (e.g., Dunham 1982; Ferguson and Fox 1984; Vitt and others, 1978); there are many factors

that influence population dynamics, including temperature, moisture, and resource availability. Nevertheless, the difference seen between years is a red flag that suggests there may be a changing lizard assemblage concomitant with the frequent droughts and increased mean annual temperature in the past decade. The species that have shown increases in this study are desert species, while some grassland/foothill species have been stable or showing decreases. Of course, there are factors besides climate change that can influence lizard distribution. Another hypothesis for a changing lizard assemblage is the weed-species hypothesis for all-female whiptails (Wright and Lowe 1968). There are three species (at least) of whiptails (*Aspidoscelis*) in the study area, including two parthenogenetic species, but only the gonochoristic species (*A. tigris*, a desert associate) is common and well-distributed along the transect, unlike *A. uniparens* and *A. flagellicauda*, which are typical of grasslands and woodlands.

This study is not limited to understanding lizard biology, as there are inferred management implications. Lizards may function as a “canary in a coal mine,” warning of impending vegetation change or identifying other environmental parameters. Even with increased temperature and decreased precipitation, some plants may be temporarily resilient (e.g., many seeds or shrubs can endure droughts, then capitalize on occasional wet years). Tracking vegetation change itself in an ecotone may be problematic (Noble 1993). Because of natural history attributes of lizards (e.g., a rapid drop in fecundity due to drought), it seems logical there will be changes in lizard populations before dramatic shifts in vegetation are seen. Such an early warning system can help land managers assess habitat vulnerabilities, so they can adjust management strategies for programs such as range or fire management (USFS 2011). Also, there are inherent uncertainties in models that predict the outcome of a changing environment on species assemblages. This study should help support or refute these predictions, refine variables and outputs, identify other factors contributing to population shifts, and contribute to adaptive management of habitat for lizards and other organisms.

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It's Lonely at the Top: Biodiversity at Risk to Loss from Climate Change

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Abstract—Climate change is a serious immediate and long-term threat to wildlife species. State and federal agencies are working with universities and non-government organizations to predict, plan for, and mitigate such uncertainties in the future. Endemic species may be particularly at-risk as climate-induced changes impact their limited geographic ranges. The Madrean Archipelago is characterized by high levels of endemism, natural fragmentation, and increasingly poor connectivity among the mesic montane islands within an arid matrix of low elevation deserts and grasslands. The region already has experienced an increase in temperature and this trend is predicted to accelerate over the remainder of the century. We assessed patterns of elevational distribution of reptiles and mammals within the Madrean Archipelago. We examined incremental temperature increases and determined how much reptilian and mammalian biodiversity is at-risk to be lost from montane islands due to elevational and geographic restriction. We estimate that 15 to 20% of all reptile and mammal diversity is at risk of loss by 2100 based solely on predicted patterns of upslope migration of biotic communities driven primarily by climate change. With this significant proportion of native species, we suggest that this emphasizes the need to continue traditional management actions focused on habitat improvement, restoration and connectivity for the majority of species in combination with innovative and active management strategies directed at the subset that is most at risk of extirpation.

Introduction

The Madrean Archipelago is characterized by extremely high levels of diversity often attributed to the geographic location at the nexus of the Chihuahuan and Sonoran Deserts and the Rocky Mountains and Sierra Madre (Gehlbach 1993). Topographic diversity is also exceptional with a basin and range landscape extending from sea level to the west and above 3,000 m on numerous peaks that create a habitat archipelago of >40 montane islands with patterns of diversity explained by island biogeographic theory (Lomolino and others 1989; Patterson 1995) and a lack of Pleistocene glaciation (Brown and Davis 1995). The Madrean Archipelago is considered to be a hotspot of evolution (Spector 2002) and biodiversity (Mittermeier and others 2005) and been labeled as a region of mega-diversity (Warshall 1995). For a number of taxa, the region harbors exceptional species diversity, often not seen at such northerly latitudes, especially among mammals (Turner and others 1995) and reptiles (Stein 2002).

General predictions for climate change suggest that most of the western United States and northwestern Mexico will experience mean temperature increases of 2-5 °C changes in mean temperature by 2100 with increases in the variability of extreme events (Easterling and others 2008; IPCC 2001). Upslope migration and changes in plant community composition (Munson and others 2012), divergent fire

regimes (Flannigan and others 2000), novel invasive species (Hellmann and others 2008), and increased disease and insect infestation (Dale and others 2001) are likely to occur and, in many cases, have already been observed. As a result, Arizona and the Madrean Archipelago are considered to be at medium to extreme risk of biome shifts (Gonzalez and others 2010) that can have profound risks for faunal communities that increase the challenges of managing for persistence under climate change scenarios.

Herein, we focus on the patterns of diversity among reptiles and mammals due to their elevated species richness in Arizona (Stein 2002; Turner and others 1995) and their reduced vagility and greater difficulty in moving between “sky islands” or other isolated habitats. Furthermore, we capitalize on the fact that these taxa are relatively conspicuous as modest to large terrestrial vertebrates and distributional ranges are reasonably well known (Brennan 2008; Brennan and Holycross 2006; Hoffmeister 1986). We conclude that a subset of the mammalian and herpetofauna found in high elevation forests are at elevated risk of extinction at least at the local level with predicted levels of climate change. However, the majority of reptiles and mammals are in habitats that will likely remain contiguous over the remainder of the century. We suggest that successful conservation strategies will require innovative approaches to deal with high elevation species in combination with traditional land management to maintain connectivity and restore degraded habitats for the majority of species.

Methods

We simulated general patterns of climate change using the digitized base map of major biotic provinces by Brown and Lowe (1981)

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

under the assumption that the lapse rate (10 °C for 1000 m in dry air, 6 °C for 1000 m in saturated air) will be the primary determinant of habitat change across elevation. While simplistic, this appears to be a reasonable approximation of the major influence on distribution of biotic communities (McDonald and Brown 1992). We down-sampled elevation data (1 arc-second resolution DEM; Sugarbaker and Carswell 2011) to ~1.2 km resolution by assigning the mean elevation of 16 raster cells to the aggregate cell. We manually reclassified elevation values into 250-m elevational intervals. To simulate the impacts of predicted warming levels, effective elevation was dropped (i.e., subtracted from current elevation) in three stages to represent moderate to severe climate impacts. Breakpoints were defined at 250 m (simulating ~2-2.5 °C change in temperature), 500 m (~4-5 °C change in temperature), and 750 m (~6-7.5 °C change in temperature). Using a polygon GIS layer of vegetation communities in Arizona (The Nature Conservancy 2004), we simulated concomitant upslope migration of vegetation communities for the southeastern corner of Arizona by assigning each polygon the most dominant vegetation type in neighboring, lower-elevation areas.

Data on species range and elevation were collected from taxon-specific treatises for mammalian (Cockrum 1960; Findley and others 1975; Hoffmeister 1986) and herpetofauna (Stitt and others 2005; Brennan and Holycross 2006; Brennan 2008). If elevations were not provided in these sources, we used topographic maps of known locations to obtain an approximate elevation. We did not include data on species associated with aquatic environments (two *Thamnophis* snakes, three *Kinosternon* turtles, three mammals (*Castor canadensis*, *Ondatra zibethicus*, *Lontra canadensis*). Furthermore, we conducted our assessments at the species level and did not address subspecies or otherwise unique population segments. We assessed the elevational range of each species and habitat affinities from the taxon-specific treatises and tallied the species at high or low risk of extirpation from Arizona by 2100 based on projected elevational shifts. For species at elevations with habitats that were likely to increase in land cover or remain as dominant biotic communities within Arizona by 2100, we considered them to be at low risk of extirpation within the State. For species at elevations with habitats that were likely to decrease in cover, we assessed the proportion of their range that would be at risk of loss using an 80% decline as threshold for high risk of loss by 2100.

Results

The area of landscape across Arizona at upper elevations represents a small proportion of the state (table 1) and upper elevations above 2250 m (~7500 ft) account for about 119,000,000 ha. Simulating temperature increases of 2-2.5 °C (250 m depression in elevation), 4-5 °C (500 m depression in elevation), and 6-7.5 °C (750 m depression in elevation) results in a substantial change in the high elevation environmental conditions statewide (fig. 1) and effectively reduces the area above 2250 m to < 13,000,000 ha (500 m scenario) by 2100. The changes in high elevation conditions within the Madrean Archipelago would result in the expansion of desertscrub and substantial decline in the coverage of all montane forest types over the next century (fig. 2). Desertscrub and grasslands would be the dominant biotic communities in the Madrean Archipelago of Arizona by 2100 (fig. 3). Given the likely increase of low elevation microclimates as well as desertscrub and grassland communities in Arizona, species associated with these elevations are projected to persist until 2100 in the face of climate change alone. This represents a majority of reptiles (83.9%, fig. 4) and mammals (76.3%, fig. 4) with no difference between the two major taxa ($\chi^2=2.38$, $df = 2$, $p > 0.20$). The risk of extirpation

Table 1—Area (ha) of Arizona terrestrial environments within 250-m elevation classes that were used as the starting point of the elevation models.

Low elevation (m)	Area (ha)
0	161404560
250	368010000
500	344429712
750	258707808
1000	293224752
1250	424730448
1500	605162160
1750	551220624
2000	248307696
2250	75723120
2500	31092048
2750	10116288
3000	1589328
3250	339552
3500	46656
3750	2304

associated with loss of habitat due to climate change was high or unclear for less than 25% of reptiles and mammals.

Discussion

Climate change is likely to have significant and rapid impacts on the Madrean Archipelago (McPherson and Weltzin 2000; Weiss and Overpeck 2005). High elevation habitats such as many conifer forests dominated by fir (*Abies*), spruce (*Picea*), and Douglas-fir (*Pseudotsuga*) are likely to decline significantly during the remainder of this century (Kupfer and others 2005; McPherson and Weltzin 2000). The rugged and diverse topography of the Madrean Archipelago will lead to the loss of many montane island-top forests and the initiation of habitat type conversion in the surrounding basins. Our simple elevational models support the projections of others that vegetation change, especially at high elevation, is likely to be substantial across Arizona by 2100.

The pace of distributional shifts is difficult to predict due to the multitude of influences. Current elevational shifts for a variety of animals suggest an upward elevation movement of 11.0 m per year at present occurs in areas experiencing the greatest temperature change, although mammals seem to be slower to move than other taxa (Chen and others 2011). However, overall species assemblage change may lag behind temperature change by decades (Menendez and others 2006). This suggests a lag time in the visibility of change and so proactive preventative management may be warranted with the knowledge that such changes are underway.

One of the greatest challenges is predicting how biotic communities will move; anticipating movements of species is even more difficult. Forests worldwide are showing a myriad of predictable and novel responses to global climate changes (Allen and others 2010). The Sonoran Desert is likely to expand although predicting the extent of the expansion is difficult as it will depend greatly on patterns of precipitation variability and increased frequency of such previously uncommon disturbances such as fire (Weiss and Overpeck 2005; Munson and others 2012). Detailed downscaled modeling efforts will provide insight to such changes (Garfin and others 2009; Tabor and Williams 2010). However, variations in phenology, phenotypic plasticity and other system responses that decouple important ecological

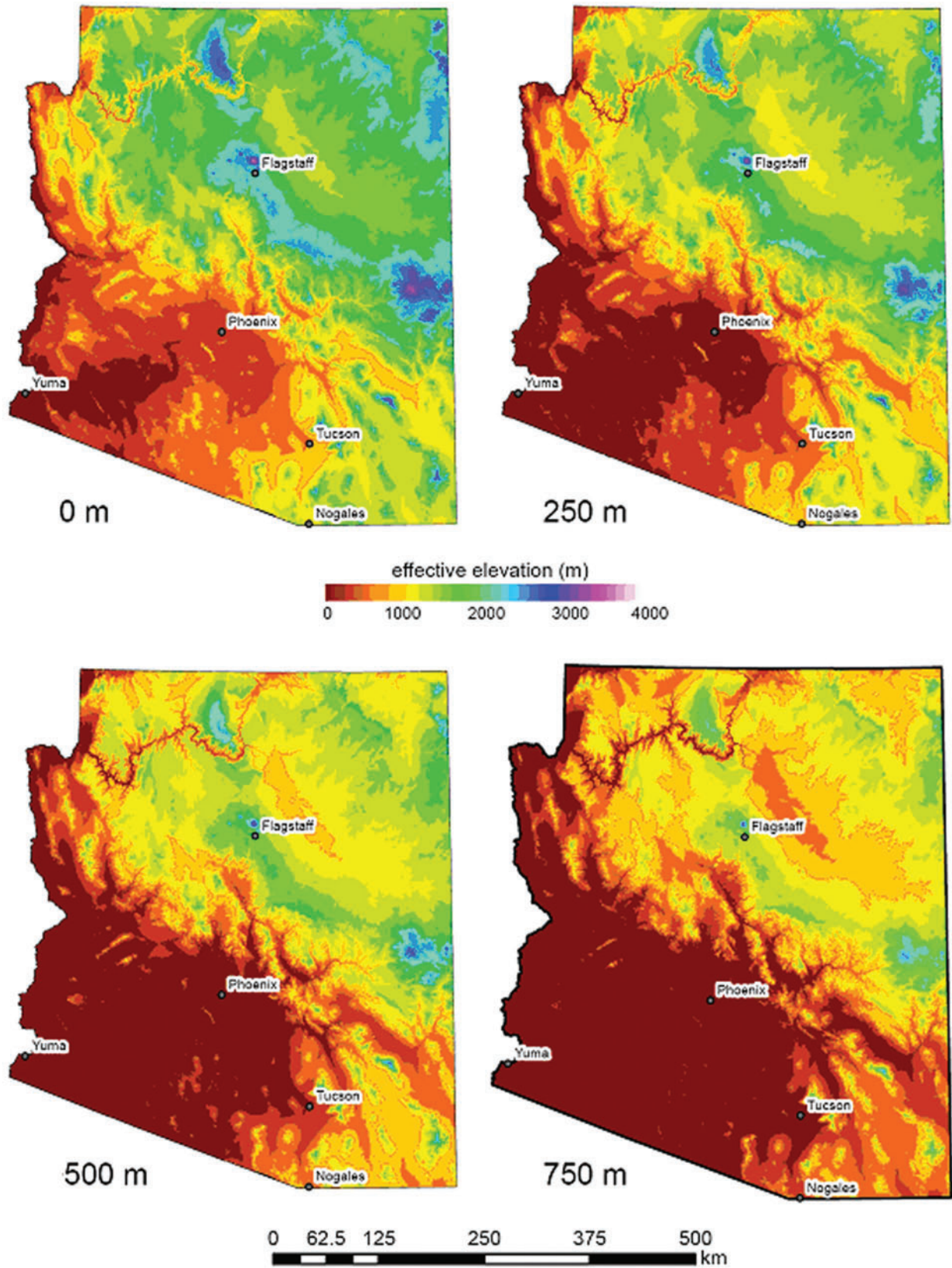


Figure 1—Elevations of Arizona with color contours at 250 m intervals for present conditions and with elevations decreased by 250 m to simulate a 2.0-2.5 °C temperature increase, 500 m to simulate a 4.0-5.0 °C temperature increase, and 750 to simulate a 6-7.5 °C temperature increase. Effective elevation presents elevations with similar colors that would be expected to have similar temperature profiles after adjustment.

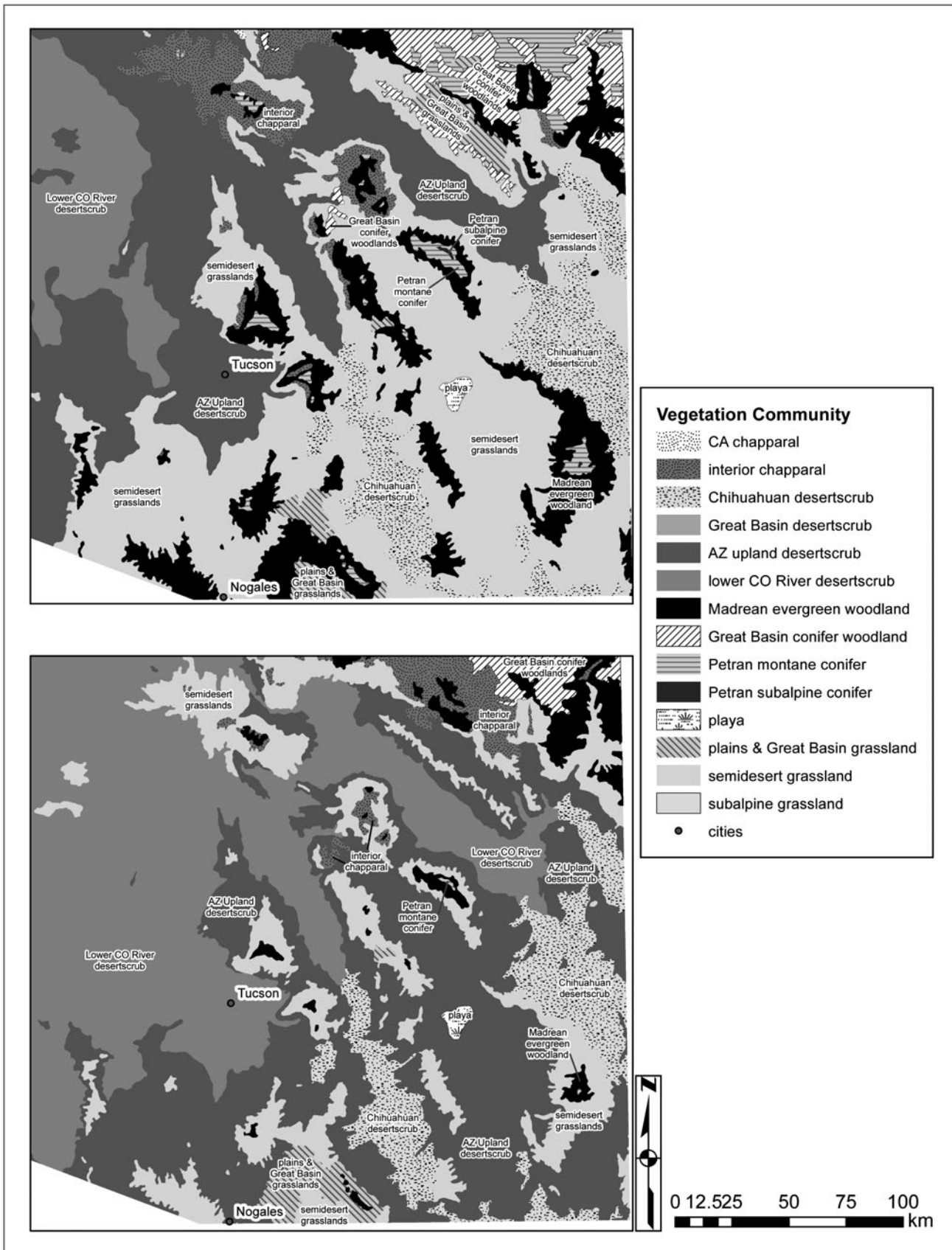


Figure 2—Distribution of biotic communities (Brown and Lowe 1981) in the Arizona portion of the Madrean Archipelago at present and potential distribution after adjusting to simulate a 4.0-5.0°C temperature change. Communities were adjusted upward in elevation by 500 m.

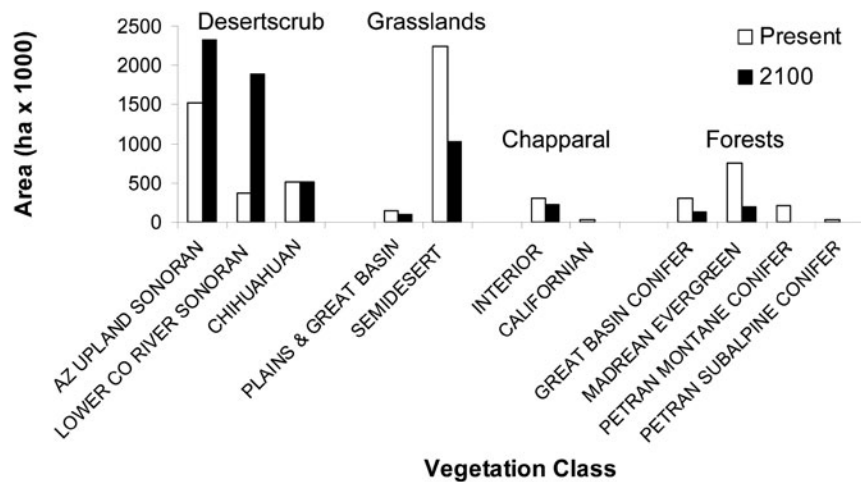
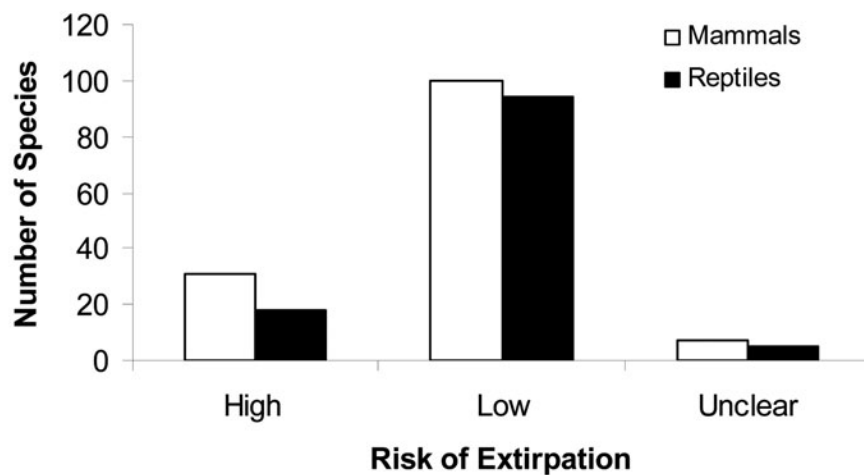


Figure 3—Potential availability of biotic communities (Brown and Lowe 1981) in the Arizona portion of the Madrean Archipelago at present and after adjusting to simulate a 4.0-5.0°C temperature change. Communities were adjusted upward in elevation by 500 m.

Figure 4—Proportion of mammal and reptile species that could lose >80% of the habitat within their current range in Arizona with a 4.0-5.0 °C temperature change simulated that would adjust communities upward in elevation by ~500 m.



associations are unpredictable and of concern (Visser and Both 2005). For instance, some organisms respond to increasing photoperiod in their annual cycles whereas temperature change can be the important cue for others (Bale and others 2002). Phenotypic plasticity and ecological flexibility in patterns of habitat use and dietary habits will also be important. We will continue to gain insight into drivers over time and such processes can clearly lead to multiple and unpredictable future stable states (Schneider 2004). Land managers must continue to act in the present but plan for the future based on this uncertainty.

Upper elevation forests are likely to decrease significantly in coverage by the end of the century under any set of projections; relic stands are likely to experience further degradation due to the plethora of factors exacerbated by climate change (Hale and others 2001). Our assessments suggest that 15-25% of the reptile and mammal species are at risk almost exclusively due to habitat loss driven by climate change. Our results did not include subspecies or isolated populations and these unique population segments should be evaluated further in the future. The vast majority of species that have isolated subspecies or unique populations are found in high elevations where the factor that maintains isolation is elevational changes in microclimate and

habitat. However, unique and disjunct population isolates outside the continuous range of low elevation species may also be identified for future conservation efforts. Some low elevation species with unique microhabitat and soil requirements such as the sand dune inhabiting fringe-toed (*Uma*) and isolated rocky outcrop dwelling night lizards (*Xantusia*) may also be targeted for more active management strategies. We emphasize that while appropriate biotic communities will remain in substantial amounts within Arizona, the species that inhabit these habitats will continue to require management to conserve habitat and mitigate current drivers of threats to biodiversity. Unpredictable responses will also undoubtedly occur and contemporary evolution in the face of climate change can in theory be significant (Hanson and others 2012). While we cannot predict the unpredictable, we must be aware that such events will occur and be vigilant.

The enormity of current and potential climate change impacts has resulted in an effective paralysis in action by many land managers, scientists, and politicians. Inaction is perhaps the least appropriate response at this point in time. Our objective was to assess the magnitude of the impacts of habitat loss due to elevational changes in comparison with latitudinal changes among two of the most diverse

yet least vagile vertebrate taxa (reptiles and mammals). Among these taxa, a minority of species (15–25%) are at high risk of loss from the fauna of Arizona by the turn of the century due primarily to the disappearance of high elevation habitats (fig. 4). A similar pattern was reported for lizards in Mexico; global loss of lizard species is estimated to be about 20% by 2080 (Sinervo and others 2010). These are the species upon which we might focus captive breeding, assisted migration, and assisted translocation efforts in the short term (Richardson and others 2009). Long-term efforts at maintaining connectivity and quality of habitat as well as habitat restoration using traditional land management techniques are what we need to continue to do for the majority of species. However, we must redouble our efforts for the temporal and spatial scales of change and levels of collaboration will not enable us to face the challenges ahead at the pace that global change occurs.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Responding to Climate Change Impacts in the Sky Island Region: From Planning to Action

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***Abstract**—Addressing the increasing effects of climate change on natural resources requires multiple organizations, agencies, and institutions working cooperatively to incorporate climate change into resource management. In the Sky Island region of the southwestern United States and northern Mexico, Sky Island Alliance, a non-governmental organization, has convened a series of climate change adaptation workshops in cooperation with a variety of partners. This paper describes a process and methodology for bringing together federal and state agencies, local governments, non-profit organizations, tribal representatives, private landowners, and academic researchers in order to develop, on-the-ground and policy-level actions through climate change adaptation planning. Key outcomes of the workshops include: identification of climate change threats to and vulnerabilities of Madrean forest, riparian, desert, and grassland ecosystems in the Sky Island region; analysis of the effects of those changes in the region (both direct and indirect) and interacting factors; a list of ecosystem specific adaptation options for the region; a plan for implementation of an adaptation strategy; and development of a regional network of professionals working cooperatively to improve natural resource management under changing conditions. This paper highlights one approach for addressing the management and conservation challenges posed by climate change through collaborative engagement at a regional scale.*

Introduction

The global oceans and atmosphere have changed due to human activities, resulting in a warmer and moister atmosphere (Trenberth 2012). As a result, the southwestern United States is among the fastest warming regions in the nation (Karl and others 2009). In the past 10 years, parts of the Southwest have warmed more than 2 °F relative to average 20th century temperatures (fig. 1). Nestled in the heart of this rapid warming is the Sky Island region of southeastern Arizona, southwest New Mexico, and northern Mexico. Sky Islands are isolated, forest-topped, mountain ranges, surrounded by lowland desert and grasslands. Characterized by steep elevation gradients, commonly from 600 m at their bases to 3,000 m at their summits, they span the gap between the Sierra Madre in Mexico and the Rocky Mountains and overlap the boundary between the Sonoran and Chihuahuan desert (fig. 2). They harbor some of the most biologically diverse ecosystems in North America.

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Effects associated with observed regional warming include a decrease in the fraction of winter precipitation falling as snow, less soil moisture, changes in timing of species' life cycle events, widespread vegetation mortality, and increased frequency of large wildfires (Robles and Enquist 2010). Temperature increases interact with other factors, such as decadal-scale drought, land use and land cover changes, habitat fragmentation, and complex ecosystem interactions.

In the U.S. portion of the Sky Island region, land tenure is a patchwork, with approximately 34 percent managed by federal agencies, 30 percent by state agencies, 27 percent in private ownership, and smaller portions managed by Native nations, local jurisdictions, and conservation interests. Although plans and mandates exist for considering climate change, individual management agencies and private entities in the region are at different stages of incorporating it into management. Many questions remain about how to implement adaptation strategies at the local level across different land management boundaries. Moreover there is a constantly expanding body of scientific information, yet it is still a challenge for natural resource managers to access science useful for planning and decision-making. In this context, work to establish cross-jurisdictional and regional coordination and to foster knowledge exchange within and across an international border is essential for building the institutional adaptive capacity needed to lessen the potential impacts of climate change (Hansen and Hoffman 2010).

Addressing these myriad challenges is the goal of *Adapting to a Changing Climate in the Sky Island Region*, a project initiated by

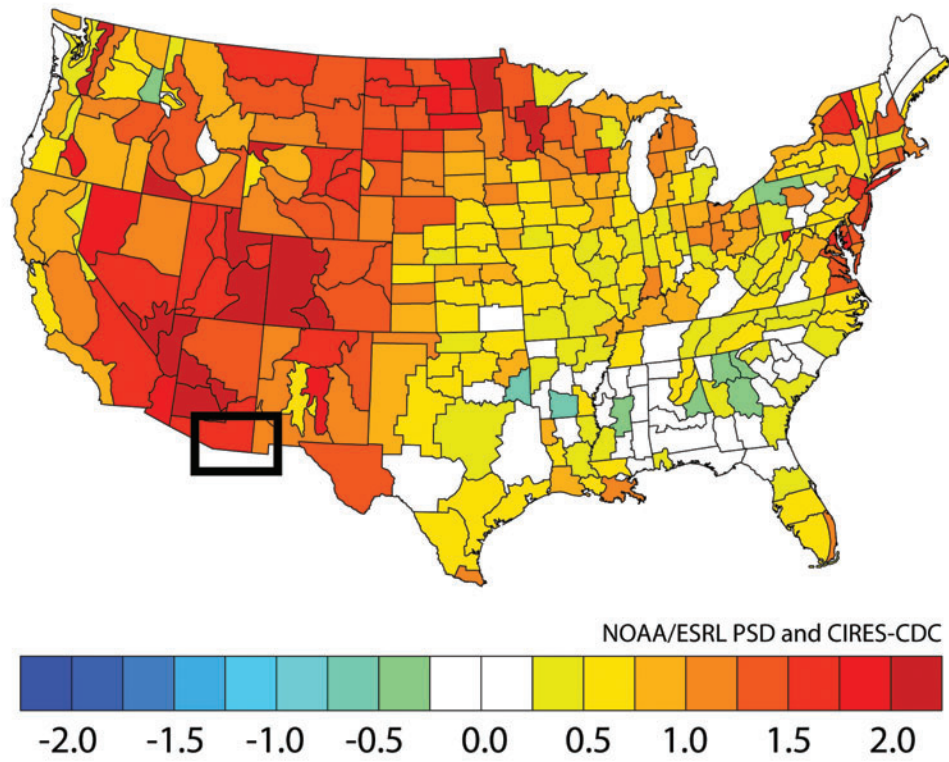


Figure 1—Composite temperature anomalies (F) Jan to Dec 2000 to 2009 Versus 1895-2000 longterm average.



Figure 2—Map of Sky Island Region.

Sky Island Alliance (SIA) in 2009, the principle elements of which include a series of regionally focused climate change adaptation workshops. Objectives of the three-part workshop series include (1) develop and implement on-the-ground and policy-level adaptation strategies that address key ecosystem management vulnerabilities, and (2) integrate climate change information into participants' planning and work. To support these objectives, a regional knowledge-action network of professionals (e.g., Jacobs and others 2010), working cooperatively to improve natural resource management under changing conditions, was created. The first two workshops in the series were convened in 2010 and 2011 and the third workshop will be convened in 2013. Participants at the first two workshops included personnel from federal, state, and local agencies; non-governmental organizations; universities; and Native nations and private landowners (table 1). Results include development and implementation of adaptation strategies that span U.S. jurisdictions. This paper describes the process used to develop and convene workshops, key workshop results, and status of post-workshop implementation.

Process and Methodology

Climate change adaptation for natural systems can be defined as a dynamic management strategy that involves identifying, preparing for, and responding to predicted climate change in order to promote system resilience, maintain system function, and provide the necessary elements to support biodiversity, human communities and sustainable ecosystem services (Theoharides 2009). To support development of climate change adaptation strategies for the Sky Island region, we worked with partners to develop and convene two workshops of a three-part series. The series was designed to involve the same agencies and individuals to provide continuity and allow for increasing depth of involvement with each successive workshop and to be of mutual benefit across jurisdictions and management mandates.

Before the first workshop, we surveyed selected natural resource managers (table 2) to assess how potential participants gather and use climate information, and to learn about their current work on climate change adaptation, and what they see as the most pressing regional climate change threats and vulnerabilities including barriers to and needs for reducing vulnerabilities. In this context, reducing vulnerability means reducing exposure and sensitivity, and increasing adaptive capacity. The survey was developed by SIA with the Climate Assessment for the Southwest (CLIMAS), Ecoadapt and the U.S. Institute for Environmental Conflict Resolution. The survey allowed us to initiate contact with potential workshop participants and gauge interest in our workshops and an Arizona Climate Change Network—our concept for a forum for communication with colleagues about adaptation and cooperative work. Of 44 question respondents, 85% indicated strong

Table 1—Climate change adaptation workshop attendees by affiliation.

	Workshop 1	Workshop 2
Federal	31 (35%)	24 (35%)
NGO	17 (20%)	22 (32%)
State	7 (8%)	2 (3%)
University	15 (17%)	10 (15%)
Other	17 (20%)	10 (15%)
Total	87	68
Repeat attendees		34 (50%)

Table 2—Affiliation of climate change adaptation survey respondents

Government agency	18 (33%)
NGO	17 (32%)
University	15 (28%)
Other	4 (7%)
Total	54

interest in both attending a climate change adaptation workshop and joining the Network. Respondents identified the following greatest threats in the region: water scarcity and drought, human pressures on ecosystems, invasive and non-native species, and fire. The greatest management needs included stable funding, a framework for dealing with uncertainty, translation of science, and effective communication among colleagues, partners and stakeholders.

In addition to our survey-development partners, we worked with the University of Arizona School of Natural Resources and the Environment and Institute of the Environment, Sonoran Joint Venture, the U.S. Bureau of Reclamation, and the U.S. Fish and Wildlife Service through the Desert Landscape Conservation Cooperative (LCC) to develop workshops that foster movement from climate change planning to action. A 2-day structure was created to deliver regionally relevant climate science and adaptation case studies (information push), followed by an interactive breakout group process (information exchange). The science delivery component addressed threats and greatest current needs identified in survey responses, while breakout groups addressed the need for better communication and coordination between jurisdictions within agencies and among different agencies and organizations in the region.

We co-convened Workshop 1, *Climate Change in the Arid Southwest* (September 2010), with the newly formed Desert Landscape Conservation Cooperative (LCC), a public-private partnership providing scientific and technical support and coordination to resource managers to address climate change and other landscape-scale stressors. Although the area encompassed by the Desert LCC (Mohave, Sonoran and Chihuahuan Deserts) is much larger than the Sky Island region, it had similar landscape-scale objectives and an overlapping group of participants. The first half-day of the workshop was dedicated to presenting region-specific information on projected climate changes, fire, water, wildlife range shifts, adaptation efforts, pre-workshop survey results, and background about the Desert LCC. Participants were pre-assigned into three facilitated breakout groups to address the following vulnerabilities and needs: water scarcity, species and habitat conservation, and research and monitoring. Each group included a diverse mix of disciplines, organizations, and management jurisdictions. The groups discussed the following series of questions:

1. What is your management goal?
2. How might climate change affect your goal?
3. How might it affect your existing strategies and methods?
4. Brainstorm actions that can be taken to reduce vulnerability.

Each group then chose two vulnerabilities for in-depth discussion of adaptation strategies.

In Workshop 2, *Between a Rock and a Hot Place* (April 2011)—co-convened with EcoAdapt—participants were assigned to ecosystem-specific facilitated breakout groups as follows: Madrean forest, semi-desert grassland, desert, and riparian. The first half-day of the workshop was dedicated to presenting information on (a) likely climate changes in the region, (b) how those changes may affect hydrology,

fire, invasive species, and connectivity and corridors, (c) vulnerabilities of species in the region, (d) a framework for dealing with uncertainty, and (e) case studies of managers incorporating climate change considerations into current work. We presented a framework for dealing with climate uncertainty in the same manner that managers and planners deal with other uncertainties. Informal scenario planning was used to consider the range of possible futures by using the models that best capture climate processes in the region of interest, noting areas of agreement while also considering extreme but plausible projections to give a sense of the potential range and direction of change. We shared an adaptive management example that specifies key uncertainties and research needed to address them, triggers for action, and necessary science and institutional structures. For the remainder of the workshop, participants developed preliminary adaptation plans in ecosystem-specific breakout groups. Groups worked through the following activities: (1) identify a specific management effort for adaptation planning and prioritize a common goal, (2) determine vulnerabilities of your goal to climate change, (3) identify a suite of potential adaptation responses, and (4) create a set of adaptation actions and next steps. They then developed hypotheses of change by answering the following questions:

1. How might climate change affect your common goal or ecosystem directly?
2. How might it affect them indirectly (e.g., ecological effects, interactions with existing stressors)?
3. How might changes outside your ecosystem influence your common goal or ecosystem?
4. Which interacting factors influence vulnerability to climate change (e.g. other physical stressors)?

At the end of the first day, there was an opportunity for each breakout group to exchange information with other groups by sharing their progress in a marketplace of ideas about key vulnerabilities and means of addressing them. We structured the second day to facilitate participants' discussion of interactions across ecosystems, landscapes, and stressors to ensure that each breakout group thought about ways in which different ecosystems and strategies influence one another. We did this to prevent groups from developing "maladaptive strategies"—i.e., strategies that addressed issues pertaining to their ecosystem, but which might adversely affect adjacent ecosystems. For the concluding session of the workshop, each breakout group presented summaries of their ecosystem goal, top five vulnerabilities, and a fully formed plan for implementing one adaptation strategy. Each plan included actions to make the ecosystem less vulnerable, identification of resources to bring the plan to fruition (e.g. data, skills, funding, materials, infrastructure, permits), identification of partners with important resources or involvement necessary for plan implementation, a timeline, and actions for monitoring success. The workshop process is summarized in figure 3.

Key Outcomes

The chief outcomes of the first two workshops included enhanced awareness of Sky Island climate change issues, an improved social network for communication and coordination, cross-agency/cross-jurisdictional discussion and common agreement on impacts and adaptation options. Workshop participants identified (a) elements of climate change likely to occur in the region; (b) the effects of those changes in the region (both direct and indirect) and vulnerabilities these effects may cause; (c) non-climate stressors, interactions between climate and non-climate factors, and interactions between

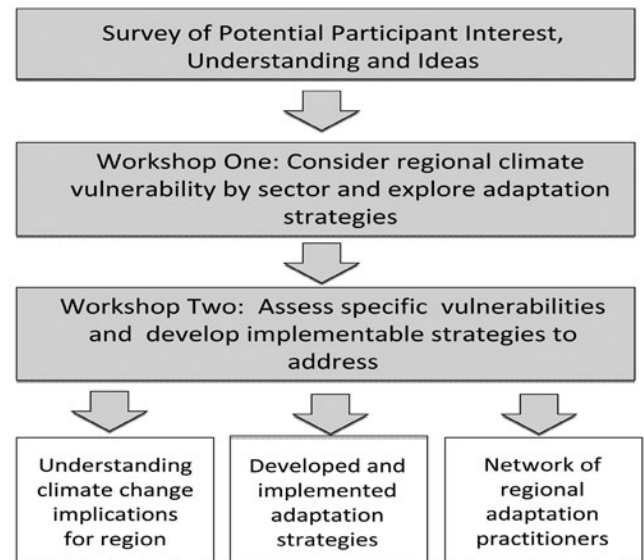


Figure 3—Flow chart of workshop process.

distinct ecosystems; and (d) prioritized initial adaptation strategies (table 3) (reports available at www.skyislandalliance.org/adaptation-workshops.htm).

The main climate threats identified by each group included increasing temperatures; precipitation factors, including amount, seasonal timing, and intensity; and interactive effects on exposure to climate through drought. The impact of the timing of seasonal precipitation is of concern because of the implications of an extended pre-monsoon arid fore-summer season: increased fire risk in all ecosystems, decreased connectivity in stream reaches, decreased dissolved oxygen in bodies of water and riparian pools, increased grass mortality, impacts on migrating birds that rely on riparian vegetation, and shifts in species composition. Participants highlighted the threat of “megadrought” to which the Southwest—which is at the *fringe* of both winter and summer moisture-bearing atmospheric circulation patterns and at the center of strong interior West temperature increases—is particularly sensitive. It was noted that megadrought could be a game changer for ecosystems, due to the potential for rapidly crossing ecosystem thresholds to new quasi-equilibrium states, such as from pine-oak forests to oak scrub woodlands, or from productive Chihuahuan Desert grasslands to semi-woody shrublands.

We note that uncertainties in climate change projections did not impede discussions about climate change effects and identification of adaptation strategies. Participants did identify critical uncertainties about what to monitor, and the necessary frequency and timing of monitoring. Through thoughtful discussion, participants identified actionable adaptation strategies (table 3) that build on existing management, restoration, and public education priorities, and—with sufficient resources—can be implemented in the short-term using familiar management tools. These are “win-win, no regrets” options for Sky Island ecosystem management.

In this brief paper, we cannot give an exhaustive accounting of the nuanced articulations of vulnerabilities, impacts, and adaptation options for each of the four Sky Island ecosystems; however, the following overview touches on important common factors and gives examples of some unique challenges. In a nutshell, Sky Island ecosystem vulnerabilities center on maintenance of ecosystem health

Table 3—Key workshop outcomes.

	Madrean Forest	Riparian Areas	Semi-Desert Grassland	Desert
Threats	↑temperatures; ↑frequency of warmer and drier winters; ↑summer precipitation variability and mega droughts	↑temperature; ↑frequency of warmer and drier winters; hotter and longer foreshummers; changes in monsoon season precipitation	↑dry winters; ↑temperatures; ↑variability in precipitation events, changes in seasonality	↑temperatures; changes in hydrology
Vulnerabilities	Forest health and function; ↑fire risk; shifts in wildlife and vegetation; loss of soil and potential for forest regeneration; ↑insect infestations	Habitat fragmentation; ↓biodiversity; alterations in physical processes, stream morphology, and water table; ↓recharge; ↓ecosystem services	Altered or diminished land use practices; flossing; ↓viable ranching; soil loss & erosion; lack of community concern for climate change effects on grasslands	Public disconnect with climate change impacts; changes in land pressure; ↑water use, ↑temperature and energy use: ↑invasive species
Adaptation Options	Manage for resilience on a landscape scale; Manage human uses of public lands; Focus resources on maintaining, and protecting resilient areas; Protect corridors for species connectivity; Close sensitive areas to prevent further disturbance; Plan for beetle detection and treatment	Capitalize on drought to reduce invasive species; Promote restoration, work with planners to build and design infrastructure that helps maintain ecosystem processes; Pursue different water policies	Show communities alternative futures (climatic/ landscape changes); Incorporate past water & land allocation information, with potential climate changes into future management; Harness mass flooding events for water reserves, ↓channelization; Change grazing time and location; and Install stabilizing features	Conduct a climate change education and awareness campaign; Engage public through citizen science projects, Harvest rainwater, Increase public transportation and bike lanes, Increase energy efficiency; Develop awareness campaign to explain relationship between fire and invasive species
Selected Adaptation Goal	Maintain ecosystem services and function of montane forests and woodlands to preserve biodiversity and adaptation potential where possible, or facilitate transition	Conserve the function and integrity of riparian systems in a changing climate for the Upper San Pedro basin	To maintain and restore grasslands and the species in them through community empowerment and engagement	Reduce human impact on desert ecosystems by awareness and outreach
Adaptation Strategy	Initiate a process to manage the Sky Island region at a landscape scale through the National Environmental Policy Act (NEPA)	“Stop the Stupid, Start the Smart” outreach campaign that places the value of water and riparian systems in terms that all different groups of people can understand	Work together to cultivate resilient, native seed sources to prepare for likely flooding and soil loss associated with climate change impacts in the region	Incorporate climate change into the Saguaro National Park BioBlitz event of 2011, specifically into the Biodiversity University

and function, keystone ecological processes (e.g., fire), species shifts, erosion, habitat fragmentation, and maintaining traditional economic land-use practices (e.g., grazing). It is interesting to note that discussions of low elevation ecosystems (grassland and desert) raised concerns about the human community’s indifference to climate change. Development of alternative land uses (e.g., energy development) was identified as increasing the vulnerability of these ecosystems and as a potential impediment to development of sufficient biological adaptive capacity. Certainly desert and riparian environments have greater exposure to human activities, such as development, recreation, immigration, and infrastructure.

Participants’ articulations of direct and indirect impacts and adaptation options accounted for much of the workshop activity. The following example from the Madrean Forest group illustrates

a workshop output. The group identified more than a dozen unique direct and indirect impacts and interactive factors, related to each of four climate threats (increased temperature, increased frequency of warm/dry winters, increased summer precipitation variability, and megadrought). A sample cascade of impacts and interactions follows:

Direct impacts: increased frequency of warm/dry winters leads to altered snow hydrology (more winter rain), diminished watershed moisture retention, increased insect invasions, increased fire risk, and vegetation shifts that favor woody species

Indirect impacts: altered phenology of aquatic at springs and increased grazing pressures

Interacting factors: policy shifts to address lack of precipitation through cloud seeding

To address this set of issues, which participants classified as “decreased forest health and ecosystem services,” six options were identified: (1) transition from project-specific planning and implementation of National Environmental Policy Act (NEPA) requirements to landscape level planning and implementation, (2) evaluate ecosystem function to prioritize management strategies, (3) restore fire appropriate regimes, (4) shift fire damage liabilities, (5) manage invasive grasses, and (6) protect resilient areas. Adjusting the scope of NEPA assessments was identified as the highest priority adaptation strategy, and a feasible plan was laid out (table 4).

A “marketplace of ideas” session, in which participants were able to interact between breakout groups, yielded insights on cross-cutting issues and interactions between ecosystems. Many ideas echoed those raised during the first workshop, but in the more action-focused context of the second workshop, they were honed and articulated more specifically. For instance, riparian areas, which exist in each of the ecosystems, are affected by watershed uplands. Disturbance to uplands and upstream reaches, such as wildland fire and water extraction, affect downstream reaches through erosion, sedimentation, and decreases in the number and extent of perennial segments. Another theme common to all ecosystems was intervention of non-climate stressors, such as water law and policy, land use and development, energy and mining policy, recreation and tourism. These stressors can increase exposure to climate changes by fragmenting habitat and reducing connectivity (as in the case of alternative energy development), or increasing fire area and intensity (as in the case of expanding wildland-urban interface). Non-climate factors are also important determinants of biological adaptive capacity. Participants identified hindrances to developing adequate institutional capacity to prepare for and respond to climate changes, including (1) attitudes of the public and key decision makers toward climate change; (2) lack of coordination and information exchange between isolated efforts to restore ecosystem function and/or prepare for climate change; (3) lack of consistency in data collection, coupled with a lack of coordination in sharing data; (4) lack of staffing, resources, and expertise to plan for and implement experimental treatments and initiatives; and (5) ineffective water and land use laws that impede efforts to enhance ecosystem resilience.

Implementation

Other outcomes from the first two workshops include the incorporation of climate change considerations into planning and project development and a more coordinated approach to preparing for climate change and restoring ecosystem function. There are a variety of adaptation planning and implementation processes currently underway in the region (table 5). Our workshops and the Arizona Climate Change Network have created a regional nexus for information sharing, project planning, and cooperative implementation that did not previously exist. For example, funding was secured to complete a *Spring and Seep Inventory, Assessment, and Management Planning Project* to gather data on biological, hydrological, geomorphological, and management status of springs and seeps in the Sky Island region. Information will then be applied to the management of sensitive and invasive aquatic species, the prioritization of restoration and conservation monies, and management of wildlife that rely on surface water. The project is being implemented by SIA in coordination with regional resource managers, including Pima County, the U.S. Forest Service, and the Spring Stewardship Institute and is receiving funding through the Desert LCC. The project seeks to reduce the vulnerability of water resources and species of concern by developing in-depth knowledge of regional spring resources, fostering cross-jurisdictional management of those resources, and prioritizing where to focus restoration and protection (table 6).

Conclusions and Next Steps

Our workshops have filled a void of regional coordination and communication about climate change effects and management responses. Assessing natural resource managers’ needs and knowledge before developing the workshops ensured effective engagement and a focus on the issues of highest importance to participants. We took a unique approach, focusing adaptation planning efforts on the entire Sky Island region rather than individual management units. This approach was beneficial in that it generated discussion and subsequent coordination across jurisdictions and management types, and resulted in identifying key common vulnerabilities and resource issues across

Table 4—Madrean forest adaptation plan.

Goal	Maintain ecosystem services and function of montane forests and woodlands to preserve biodiversity and adaptation potential where possible, or facilitate transition.
Strategy:	Manage the Sky Island region at a landscape scale by implementing a programmatic National Environmental Policy Act (NEPA) analysis. Conduct a landscape vulnerability assessment, define project areas, and use a facilitated process with a conflict resolution expert.
Rationale:	Consider landscape scale instead of single places in specific jurisdictions. Develop a programmatic NEPA analysis to manage for resilience. The FireScope model could inform management at a landscape scale.
Resources Needed:	Working group for coordination: State agencies, Government agencies, Counties, Non-profit organizations, such as Sky Island Alliance, Land Conservation Trusts, Tribes, Sonoran Joint Venture, Universities, such as the University of Arizona, State forestry groups, Private land owners
Lead:	U.S. Forest Service
6-9 months:	Define and assess landscape using FireScope tool, identify resources, build partnerships.
6-24 months:	Organize and engage working group to develop landscape NEPA analysis.
24-36 months:	Draft programmatic NEPA analysis, stakeholder outreach, implement public comments, and prepare final.
Monitor Success:	Track the timeline and process in getting the NEPA decision adopted in the region. Track implementation and revise if necessary.

Table 5—Related adaptation efforts.

Adaptation Efforts	Lead Organization
Sonoran Desert Conservation Plan	Pima County
Climate Change and Natural Resources in Pima County	Pima County
Las Cienegas National Conservation Area Climate Change Adaptation and Scenario Planning	Bureau of Land Management and The Nature Conservancy
Greater Southlands Habitat Conservation Plan	City of Tucson Office of Conservation and Sustainable Development
Cuenca Los Ojos –Restoration	Cuenca Los Ojos
Firescape	University of Arizona and Coronado National Forest
Coronado National Forest Land and Resource Management Plan Revision	U.S. Forest Service Rocky Mountain Research Station and Coronado National Forest
Sky Island Region Climate Change Adaptation Workshop Series	Sky Island Alliance
Sky Island Spring and Seep Inventory, Assessment and Management Planning Project	Sky Island Alliance

Table 6—Implementation case study.**Spring and Seep Inventory, Assessment, and Management Planning**

Threats	↑ temperatures, ↑ aridity, ↑ scarcity of water that supports wildlife and biological diversity
Vulnerabilities	Lack of data on condition of springs/seeps, alteration of springs/seeps for human uses, likely inability of managers to maintain water where it currently exists
Adaptation Strategy	Conduct field-based assessment of spring/seep condition, species present, water quality and quantity, solar exposure and human alteration; identify appropriate restoration and protection activities
Project Partners	Lead- Sky Island Alliance, Spring Stewardship Institute, Pima County, Pima Association of Governments, Arizona Game and Fish Department, The National Park Service, The Nature Conservancy, U.S. Bureau of Land Management, U.S. Fish and Wildlife Service, Ft. Huachuca, Coronado National Forest, U.S. Geological Survey, Arizona Water Resources Research Center, Desert LCC
Implementation Activities	
Nov 2011 – May 2012	Determine areas of high management priority for conducting assessments with project partners
Apr 2012	Train volunteers and agency personnel in spring/seep assessment protocols
May 2012 - Aug 2013	Utilize volunteers to assess 50 springs in high-priority areas
Apr 2012 – Ongoing	Work with agency personnel and complementary projects to assess springs/seeps being visited for other projects
Nov 2011 – Aug 2013	Develop a regional spring/seep online database accessible to all jurisdictions
Aug 2012 - Ongoing	Direct restoration and protection money and efforts to newly prioritized springs, and incorporate new spring data in project planning (e.g. prescribed fire)
Jan 2013	Implement restoration of natural flow and vegetative structure on 12 priority sites

the region. It also afforded managers a sense of how their activities may affect neighboring resources. Convening workshops and creating a knowledge-action network has fostered ongoing sharing of project work, information and expertise. One year after the 2011 workshop, it is clear that adaptation project implementation is most successful when there is a dedicated lead organization with time and resources to advance the project. Continually integrating emerging science on regional climate change and its impacts into management planning and project implementation will be an ongoing challenge.

The next steps for this initiative include: a final workshop in 2013 to share updates on project implementation from the previous two workshops, further development and expansion of the Arizona Climate Change Network to the entire Sky Island region, and further implementation of adaptation projects, and incorporation of climate change information into regional management.

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Southwestern Cienegas

Flora and Vegetation of the Saint David and Lewis Springs Cienegas, Cochise County, Arizona

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Abstract—In the Sky Island region, cienegas are rare marshlands amidst arid surroundings where ground-water perennially intersects the surface. Their unique physical properties give rise to a characteristic plant community dominated by wetland graminoids. Evaporation usually causes the water to be alkaline, and vegetation around a cienega commonly includes halophytes and other unusual species. Depending on their age and size, they may also harbor high levels of endemism. Cienegas are far from pristine, and like many wetlands and riparian areas, they have probably been exploited for millennia. In the American Southwest, these habitats are hypothesized to have been in severe decline over the past 150 years due to a variety of man-made factors. In light of their biological and cultural importance, it is important to learn as much as we can about their current condition and conservation potential.

Introduction

Cienegas, described by Hendrickson and Minckley (1985), are mid-elevation wetlands (3280-6560 ft.) characterized by permanent, scarcely fluctuating water sources amid arid surroundings. The aquifer dynamics, floral, and faunal characters of cienegas are unique and vary according to regional geomorphological and ecological constraints. Cienega-type marshes and wetlands form where layers of rock or impervious clay hold water at the surface or through the continuous upwelling of numerous small springs and seeps (USDI 2012). Cienegas can be very large and harbor high levels of endemism, such as Cuatro Cienegas in Coahuila, Mexico, with an area of approximately 208,000 acres (325 mi²); or small and cryptic <2 acres (0.003 mi²), such as the Lewis Springs Cienega in Cochise County, Arizona.

The soils of cienegas are typically finely textured, and highly organic. Moisture, salinity, and other abiotic factors are also important influences on species composition. The result is a characteristic suite of plants specially adapted to these conditions, a rare plant community dominated by wetland graminoids (monocots) in three main families: grasses (Poaceae), rushes (Juncaceae), and sedges (Cyperaceae).

Saint David Cienega

The San Pedro National Conservation Area (SPRNCA) is a narrow strip with approximately 40 miles of stream running from the Mexican border to the town of St. David, Arizona. Among the plant communities of the SPRNCA are two separate cienega habitats: the St. David

Cienega at the northern tip and a little known, much smaller wetland near the middle associated with the Lewis Springs and Government Draw drainages (fig. 1).

The St. David Cienega is a marshy flat of approximately 350 acres with a perimeter of 2.3 miles. Seasonality is an important factor, and cienegas can vary dramatically depending on time of year. The main portion of the wetland with permanent water is about 75 acres (figs. 2, 3).

Surrounding vegetation is a mixture of mesquite grasslands, bosques, and Chihuahuan desert scrub. Saint David Cienega would be completely vegetated with no visible surface water; however, there is currently active management (vegetation removal and earth moving) in a northwest portion to provide open water for native fish and frog habitat (Simms, personal communication). Figure 4 is a landscape schematic of the vegetation zones of the St. David Cienega. Species associations are influenced by a moisture gradient from perennially saturated soils in the middle, where the water intersects the surface, to a seasonally dry and increasingly saline periphery. *Schoenoplectus americanus* (chairmaker's bulrush) forms nearly impenetrable stands throughout the middle portion, associated with *Lythrum californicum* (California loosestrife), and *Berula erecta* (cutleaf water parsnip). This zone has ankle-deep water throughout with organic, black soils (fig. 5). Moving outward, dense clumps of *Carex praegracilis* (clustered field sedge) dominate along with *Eleocharis rostellata* (beaked spike rush) (fig. 6). A mix of *Muhlenbergia asperifolia* (alkali muhly), *Distichlis spicata* (salt grass), and *Juncus arcticus* var. *balticus* (Baltic rush) can be found in the "Juncus-Distichlis" zone; transitioning into an area of tall grasses such as *Sporobolus wrightii* (sacaton), *Panicum obtusum* (vine mesquite), and *Bothriochloa laguroides* ssp. *torreyana* (silver beardgrass). Mesquite (*Prosopis velutina*) and sacaton outline much of the perimeter of St. David Cienega.

There are naturally various species that can be patchy and locally abundant, such as *Anemopsis californica* (yerba mansa), *Asclepias subverticillata* (whorled milkweed) and *Helianthus annuus* (common sunflower). In the northwestern section of the cienega *Typhadomingensis*

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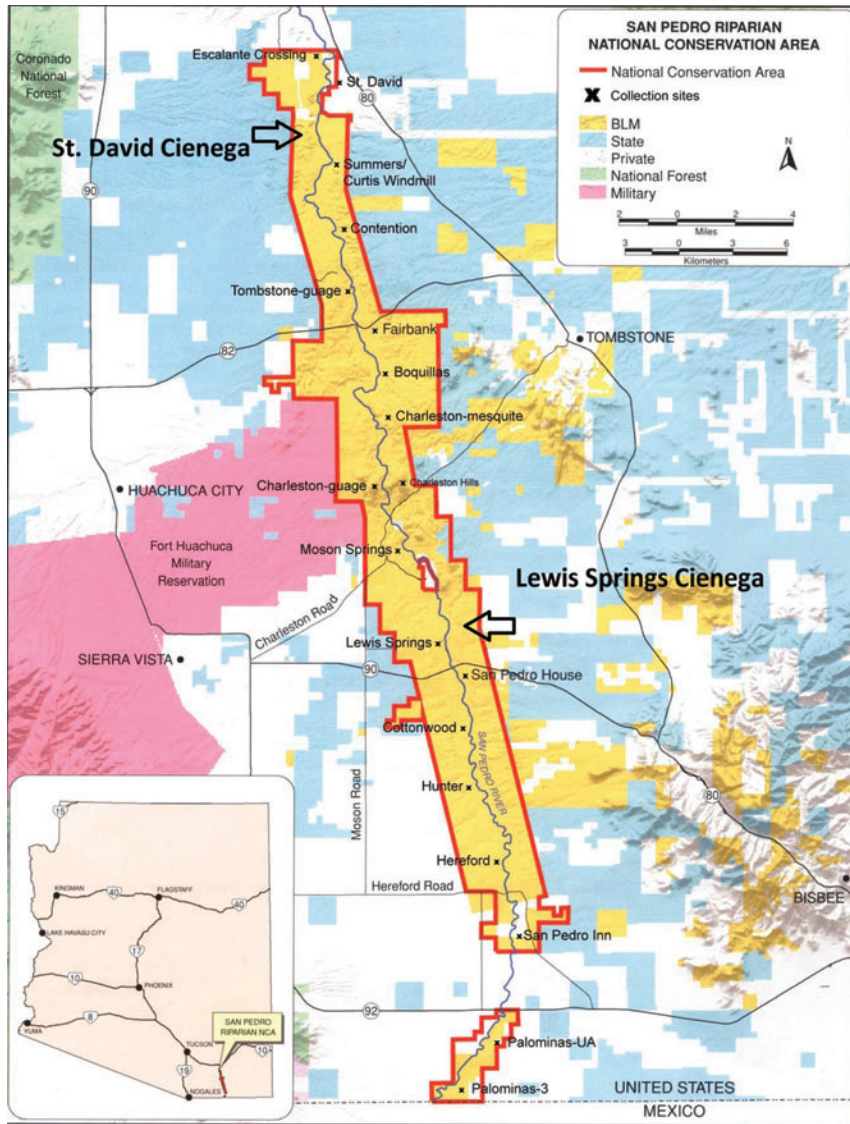


Figure 1—St. David and Lewis Springs Cienegas within the San Pedro National Conservation Area.



Figure 2—St. David Cienega looking northwest; Whetstone Mountains in the background (photo taken July 2005).



Figure 3—Similar perspective of St. David Cienega (fig. 2) taken April 2012.

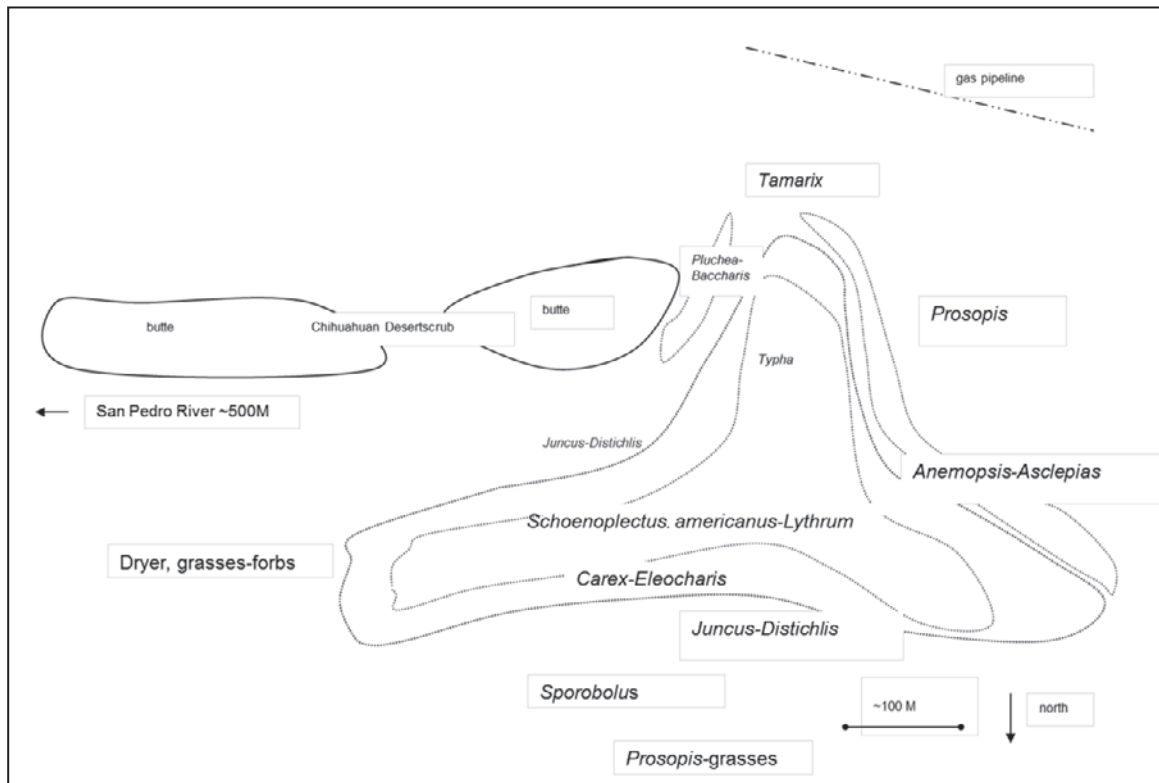


Figure 4—Schematic of St. David Cienega vegetation zones.



Figure 5—Nearly impenetrable stands of chairmaker’s bulrush (*Schoenoplectus americanus*) in Middle portion of St. David Cienega.



Figure 6—Mats of clustered field sedge (*Carex praegracilis*) in the ‘Carex-Eleocharis’ zone of the St. David Cienega.

(southern cat-tail) replaces *S. americanus* as the dominant wetland graminoid.

Cycles of saturation and evaporation tend to make soils alkaline, and vegetation in cienegas almost always includes halophytes and other specialized plants. The St. David Cienega has numerous examples of species with high fidelity to cienegas—their vernacular often indicating salt tolerance e.g., *Almutaster pauciflorus* (alkali marsh aster), *Distichlis spicata* (salt grass), *Muhlenbergia asperifolia*, *Pluchea odorata* (saltmarsh fleabane), *Symphotrichum subulatum* var. *ligulatum* (salt marsh aster), *Suaeda moquinii* (seablight), etc.

A floristic inventory was conducted during the early 2000’s of the SPRNCA and 625 taxa were vouchered from that study (Makings 2006). Table 1 is a list of 23 of those from the St. David and Lewis Springs Cienegas that were found nowhere else but in these two habitats. Some, no doubt, can be dismissed as simply rare and/or overlooked in the greater SPRNCA, but others might be considered true cienega indicators. For example, in Cochise County, *Almutaster pauciflorus*, *Ammannia coccinea*, and *Muhlenbergia asperifolia* have only been collected from cienegas of the region. Using biodiversity occurrence data accessed through the Southwest Environmental Information

Table 1—Species found only in cienega habitats within SPRNCA.

Species	Cienega location
<i>Almutaster pauciflorus</i> ^a	St. David / Lewis Springs
<i>Ammannia coccinea</i> ^a	St. David
<i>Anemopsis californica</i> ^a	St. David / Lewis Springs
<i>Berula erecta</i> ^a	St. David
<i>Calystegia sepium</i> ^{a,b}	St. David
<i>Carex praegracilis</i> ^a	St. David
<i>Chamaesyce prostrata</i>	St. David
<i>Cirsium vulgare</i>	St. David
<i>Cyperus spectabilis</i>	St. David
<i>Distichlis spicata</i> ^a	St. David
<i>Eleocharis rostellata</i> ^a	St. David
<i>Elymus trachycaulus</i> ^a	St. David
<i>Epilobium ciliatum</i> ^a	St. David
<i>Eryngium sparganophyllum</i> ^a	Lewis Springs
<i>Leptochloa fusca</i> ssp. <i>fascicularis</i> ^a	St. David
<i>Lobelia cardinalis</i>	Lewis Springs
<i>Lythrum californicum</i> ^a	St. David / Lewis Springs
<i>Mentha spicata</i> ^a	St. David / Lewis Springs
<i>Muhlenbergia asperifolia</i> ^a	St. David / Lewis Springs
<i>Pluchea odorata</i> ^a	St. David
<i>Pluchea sericea</i>	St. David
<i>Samolus valerandi</i> ssp. <i>parviflorus</i>	St. David
<i>Sisyrinchium demissum</i>	St. David

^aHigh fidelity to cienegas and similar wetlands.

^bState record.

Network (SEINet 2012), this overlapping distribution pattern is consistent with many other taxa in table 1. In addition to the cienegas of the San Pedro, they regionally tend to be found in such places as Empire Cienega in Las Cienegas National Conservation Area (Pima County), O'Donnell Cienega in the Canelo Hills (Santa Cruz Co.), San Rafael State Natural Area (Santa Cruz County), Hooker Cienega (Cochise County), and Pipe Springs Cienega in the San Bernardino National Wildlife Refuge (Cochise County).

Lewis Springs Cienega

The Lewis Springs Cienega is approximately 1300 ft. east of the San Pedro River and just south of the Lewis Springs/Government Draw drainage. It is an unlikely wetland situated on the side of a small slope, probably maintained by gravity-driven subterranean flow from surrounding uplands. The margins of the wetland are abrupt and the contrast of desert vs. wetland vegetation is especially evident in the dryer months (fig. 7).

The Lewis Springs Cienega is a little less than 2 acres, but has yielded several species of interest, including ones that appear to be limited to this tiny wetland. For example, *Lobelia cardinalis* (cardinalflower), an obligate wetland species, is only known from this isolated population at Lewis Springs, and nowhere else along the SPRNCA floodplain. Also notable, is *Andropogon glomeratus* (bushy bluestem), a tall perennial grass that is rare regionally, but abundant here. 'Cienega indicators' such as *Almutaster pauciflorus*, *Anemopsis californica*, *Lythrum californicum*, *Mentha spicata* (spearmint), and *Muhlenbergia asperifolia* are also only present here or in the St. David Cienega, and not in the greater SPRNCA.

The most noteworthy species in the Lewis Springs Cienega is *Eryngium sparganophyllum* (Arizona eryngo), an unusual dicot in the Apiaceae. *Eryngium sparganophyllum* is a perennial herb with a basal rosette of long, parallel-veined leaves. The flowers are cream and clustered in dense heads at the end of the branching, scapose inflorescences (fig. 8). *Eryngium sparganophyllum* is a rare, regional endemic that occurs in marshes and other riparian habitats. SEINet data shows only 15 collections of vouchered material from the region—In Arizona, from Pima and Cochise Counties; In Mexico, one locality each from Sonora, Coahuila, and south to Durango (fig. 9). Other biodiversity data such as NatureServe (2012) report the global range to include Zacatecas and Jalisco, which would be slightly farther south, but regardless of its distributional limits, the scant number of collections suggests a rare life history strategy for this species. *Eryngium sparganophyllum* can reach a height of >5 ft. and is conspicuous when flowering, and therefore, it is hard to imagine that this plant is overlooked in the field. In fact, there are



Figure 7—Lewis Springs Cienega looking northeast. Most abundant species are *Juncus arcticus* var. *balticus* and *lythrum californicum* (California loosestrife) (post-monsoon photo taken in October 2011). Grass along perimeter is mostly alkali sacaton (*Sporobolus airoides*).



Figure 8—*Eryngium sparganophyllum* (Arizona eryngo).



Figure 9—Distribution of *Eryngium sparganophyllum* with locality (collector and date).

anecdotal comments on several labels noting its localized abundance (e.g., Yatskievych in 1982: “dominant in marshy meadow”; Reina in 2003: “very common herbaceous perennial”; Wiens in 2008: “locally common herbaceous perennial...”) The limited distribution, coupled with such narrow ecological parameters, also make *E. sparganophyllum* especially susceptible to local extinction, earning its status as “critically imperiled” in Arizona, and “possibly extirpated” in New Mexico (NatureServe 2012). Indeed, Wooton and Standley, in their treatment of the New Mexico flora in 1915, note the only collection of *E. sparganophyllum*, a Charles Wright type specimen from “Las Playas Springs, near the Sierra de las Animas, New Mexico,” probably the present day Playas Valley east of the Animas Mountains in the New Mexico “Bootheel” (Wooton and Standley 1915). In addition to this population, probably many others have been extirpated due to dewatering of wetlands in the region.

Discussion

Cienegas and their environs have been inhabited for millennia and have great archaeological and biological value. However, the future of cienegas is uncertain, having been greatly reduced over the last 150 years mainly due to the influences of humans. Cienegas may be one of the most endangered habitats in the American Southwest and northwestern Mexico, many only remnants of their historical condition.

Hendrickson and Minckley (1985) estimate habitat loss of cienegas to be upwards of 95%, making them aquatic islands in an arid matrix. Frank Crosswhite, editor of *Desert Plants* at the time, noted, “Cienega sites were the first to be usurped by land-hungry Hispanics and Anglos alike who developed large herds of cattle to devour the vegetation and drink the water. Overgrazing made the cienega locations among the most mistreated sites on earth. A variety of misfortunes, brought about either knowingly or unconsciously by man, have resulted in drainage, arroyo cutting, and general destruction of these unique habitats” (Crosswhite 1985). Cattle grazing, development, and associated water extraction (groundwater pumping, draining, diverting, impounding, etc.) continue to be problems and have increasingly placed pressures on the ecological integrity of many cienegas, including those along the San Pedro River valley.

Cienegas are relatively small ecosystems with important roles on the landscape, yet ironically, poorly understood. In order to assess their importance and conservation potential, better knowledge regarding proper functioning of these sites is critical, including investigation of their extent, ecology, and abiotic parameters, as well as monitoring their trends. The survival of the St. David Cienega, Lewis Springs Cienega, and other rare wetlands of the region will ultimately depend on (1) a demand for thoughtful choices about where and how much groundwater is pumped, (2) greater emphasis on research, and (3) our support of efforts to protect and restore them.

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Paleoenvironmental Framework for Understanding the Development, Stability, and State-Changes of Ciénegas in the American Deserts

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Abstract—As persistent wetlands in arid regions, *ciénegas* represent important resources for the maintenance and preservation of regional biodiversity. The history of *ciénegas* in the American Southwest over the last 8,000 years provides information on the dynamics of growth, longevity, and stability of these habitats under previous climate conditions. Proxy data such as sedimentology, pollen, charcoal, and isotopes preserved in *ciénega* sediments provide information on the formation, disturbance, resilience and state changes within these systems. This long-term perspective is compared to the recent history of degradation observed in the region. Once formed, *ciénega* surfaces alternate between wetland and dryland phases, identified by changes in pollen preservation and isotopic signatures. These phase changes are hypothesized to be controlled by groundwater-table depths. The degraded state of many extant *ciénegas* may be similar to the dryland phase, but may also require active management to initiate the natural hysteresis of wetland and dryland phases. We present a conceptual model on the controls for different *ciénega* states and how the paleoenvironmental record of change can be used in conservation, restoration, and management of these critical habitats.

Introduction

Arid and semi-arid environments occupy 40% of the terrestrial land area and represent regions with the highest human population growth rates (18.5% between 1990 and 2000; Hassan and others 2005). This population growth places great pressure on the natural environment and the ecosystem services it provides, particularly in terms of water provisioning and water and erosion regulating services. Additional future pressure will come with warming temperatures projected to reduce global streamflow by 15% with every 1°C of temperature rise due to the combined effects of increased evaporation and decreased precipitation (Henderson-Sellers and McGuffie 2012). Beyond fundamental ecosystem services, wetlands (*ciénegas*) of the American Deserts have long been identified as regions of high conservation concern (Abell and others 2000; Hendrickson and Minckley 1985; Leopold 1949; W. Minckley 1969, 1992).

High endemism associated with some *ciénegas*, most famously the wetland complexes of the Cuatrociénegas Valley, Coahuila Mexico (Abell and others 2000; Badino and others 2004; W. Minckley 1969,

1992), have made these environments a conservation priority. Less considered are smaller *ciénegas* across the Chihuahuan, Sonoran, and a lesser extent Mojave deserts. For example, in Arizona where wetland environments occupy ~2% of the land area they are critical habitat for at least 19% of the threatened, candidate, or endangered species within the state (Baker Jr. and others 2004; T. Minckley and others *in review*). However, beyond species of concern, simply by providing different habitat in otherwise arid regions, desert *ciénegas* and riparian corridors may increase regional biodiversity by up to 50% (Sabo and others 2005).

At present, there is no systematic understanding of the dynamics that promote the natural formation and resilience of *ciénegas* as a biogeomorphic unit within fluvial systems. However, the literature on *ciénega* establishment, development, and resilience has increased in recent years (Brunelle and others 2010; Heffernan 2008; Heffernan and others 2008; Heffernan and Fisher 2012; Minckley and Brunelle 2007; T. Minckley and others 2009, 2011). Here we present the current understanding of *ciénega* growth and development in the American Deserts. We focus on the paleoenvironmental record of *ciénega* origination and use those data to construct a model of natural *ciénega* dynamics compared to their current degraded state, which form the basis for the management and restoration challenges we presently face.

Prior to EuroAmerican settlement, the American Deserts contained many *ciénegas*, near piedmonts, as in Cuatrociénegas, or as emergent features within regional river systems as is seen in many *ciénegas* in Arizona and New Mexico (fig. 1) (Hendrickson and Minckley 1985;

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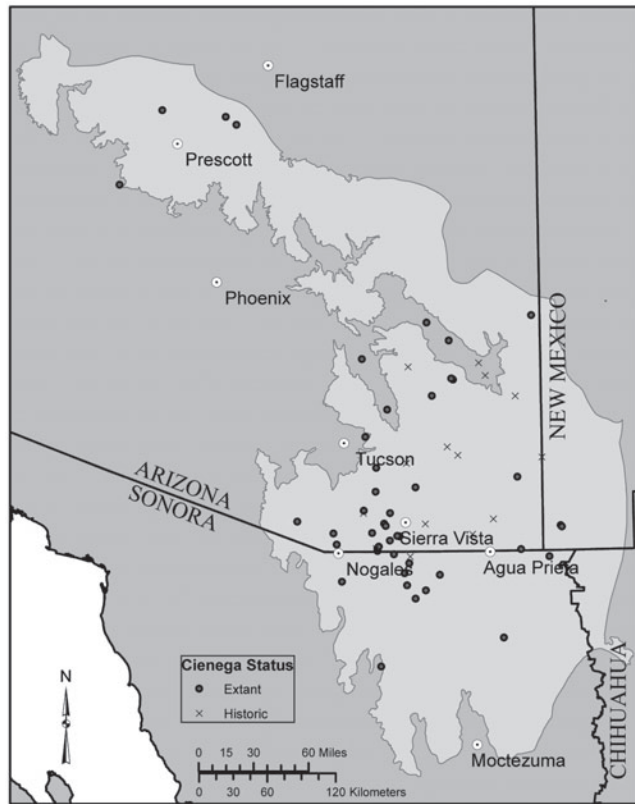


Figure 1—The distribution of the Apache Highland Grasslands and historic and extant ciénegas in southern Arizona, USA, southeastern New Mexico, USA, northern Sonora, Mexico, and northeastern Chihuahua, Mexico.

T. Minckley and others, *in review*). The loss and degradation of these habitats increased rapidly with human settlement, influenced by removal of beaver and their associated dams, draining and conversion to pasture and agricultural fields, down-cutting along nick points in wagon and rail roads, and active channelization and draining to reduce regional malarial threats in the late 19th and early 20th centuries (Bryan 1925, 1928; Fonseca 1998; Hendrickson and Minckley 1985; Leopold 1949). Later impacts on ciénegas include headcuts resulting from artificial dam installations, which concentrated flood pulses and increased associated erosive force of those events (fig. 2). Current threats are associated with both these legacy impacts and groundwater overdrafts that result in a loss of surface connectivity between the water table and root zone. The pattern of regional ciénega degradation is shown by comparison of historic vs. extant ciénegas in southeastern Arizona (fig. 1). Many of these former ciénegas are located in the major agricultural region of Cochise County, AZ (fig. 1). Cumulatively the activities associated with settlement have resulted in a general degradation of ciénegas by converting many into grasslands and shrub-lands dominated by mesquite (*Prosopis* sp.) and other desert trees and shrubs.

Geomorphic Settings Of Ciénegas

Ciénega refers to a set of freshwater environments in the North American deserts and semi-arid grasslands that are typically permanently wetted, either by springs or by water forced to the surface by channel constrictions or sub-surface features such as bedrock or sills (Heffernan 2008; Hendrickson and Minckley 1985; T. Minckley and



others, *in review*). Flow of subsurface water is distributed laterally and longitudinally, allowing ciénegas to occupy areas 100's of meters wide and long. For example, the San Bernardino Ciénega, spanning the border between Arizona and Sonora, is estimated to have been 1.0-3.4 km wide and 6 km long (Rosen and others 2005), while Canelo Hills Ciénega is 0.1-0.14 km wide and ~2

km long. Because the subsurface controls of ciénega formation are not well known, the proposed spring classification system of Springer and others (2008) presently best describes these environments as 'low gradient wetlands with indistinct or multiple [water] sources.' Ciénegas, though aggradational (Minckley and Brunelle 2007; T. Minckley and others 2011), do not appear to be formed through anastomosing streams with associated terracing (Leopold and others 1994). Rather, ciénegas appear largely planar, occupying nearly the entire widths of valley bottoms with little large-scale morphology to distinguish sub-units within these surfaces. However, preferential flow channels can exist across the surface between hummocks of grasses, sedges, and other herbaceous taxa. Aerial photographs of extant ciénegas show that these features within low-ordered streams and rivers have distinguishable paleo-stream channels disappearing above and dendritic channels emerging below permanently wetted ciénega, creating a more deltaic-like form than a distinct channel form.

Ciénega surfaces appear to have a strong biogeomorphic control on their formation. Heffernan (2008) proposed that ciénegas represent an alternative stable state to gravel bottom stream channels that



Figure 2—Downstream view from head cut of incised channel near Cloverdale Ciénega, NM. Brown, thin, paleo-ciénega soils are evident on left bank downstream margin. Poorly sorted and angular rocks and cobbles make up the bed material nearest to the head cut.



Figure 3—“Flow-Lines” across the Canelo Hills Ciénega, March 2009.

characterize many of the river corridors of the American Deserts. Heffernan (2008) observed that after 4 years without grazing pressure, wetlands had developed in over 20% of Sycamore Creek, Tonto National Forest, Arizona. Large flood events ($>20\text{m}^3\text{ s}^{-1}$) within Sycamore Creek were able to remove up to 76% of the nascent vegetation cover in single events, but most lower magnitude flood events ($<20\text{m}^3\text{ s}^{-1}$) only affected 20% of the vegetation cover. How longer established ciénegas respond to floods is not known, but the few analyses in progress argue for long-term surface stability.

Extant ciénegas, such as Canelo Hills Ciénega, show post-flooding evidence of laminar flow avulsing from a “main-channel” that lays aboveground vegetation down across the entire surface with no evidence of scouring to bedrock (fig. 3). This suggests that a combination of lateral spreading of flood-pulses and aboveground biomass attenuates the erosive strength of floods and protects softer sediments of the ciénega surface. Flood events bring in sands, silt and clays, and may be an important source of fine organic detritus from upstream sources (Heffernan and others 2008). During non-flood season, the permanently wetted soils and slow movement of water through the vegetation matrix of a ciénega provides an environment for capturing and retaining pollen and other micro and macro botanical remains that allow for the reconstruction of paleoenvironmental histories (T. Minckley and others 2011). Based on consistencies in organic content from a transect of sediment cores from Canelo Hills Ciénega, it appears that the entire vegetated surfaces of ciénegas may grow synchronously when climatic and hydrologic conditions are right for wetland initiation (Berg-Mattson and others, in prep).

Paleoenvironmental Study

T. Minckley and others (2011) looked to expand upon Heffernan’s (2008) multiple stable state hypothesis by applying the interpretation of multiple stable states to the 8000 year long San Bernardino Ciénega paleoenvironmental record. Instead of a gravel bottom stream transitioning to a wetland, stabilization of the sand bottom matrix appears to have occurred ~ 8.0 ka (ka = calibrated *kiloannum* years before 1950 CE) during a dry phase where pollen was poorly preserved and herbaceous taxa and desert trees dominated (fig. 4). Evidence of perennial water on the surface begins ~ 7.0 ka and persisted until ~ 4.0 ka based on pollen preservation and observed aquatic snail shells in

the sediments. After 4.0 ka, pollen preservation decreases suggesting aerial exposure of the ciénega until ~ 2.4 –1.6 ka BP. Isotopic analysis of this section confirms that the surface was likely occupied by grassland vegetation (fig. 4) (T. Minckley and others 2009). A return to a wetland state occurs after 2.4–1.6 ka BP based on pollen preservation and isotopic analyses, which likely persisted until the late 19th to early 20th century (Mearns 1907; T. Minckley and others 2011).

Discussion

Extending observations of modern riparian and ciénega dynamics into the past requires placing interpretations of available proxy (pollen, isotopes and sediment characteristics) into a testable framework (fig. 5a, b) where there are three possible ciénega states: historically natural dryland and wetland phases, and a recent degraded phase. Dryland phases and degraded phases appear similar in the pollen record having poor pollen preservation and, therefore, only provide minimal presence-absence vegetation data based on the most hardy pollen grains (T. Minckley and others 2011). These data are not considered quantifiable by the authors. Pollen preservation is enhanced during the wetland phase, providing a first order estimation of whether a surface was saturated in the past. Wetland phases, then, are those that provide the best data for composition of the plant communities for both ciénegas and surrounding uplands.

Isotopic analysis of ciénega sediments provides evidence of state changes based on identification elemental and isotopic sources of organic material (Meyers 1994; T. Minckley and others 2009). Though not taxonomically specific, isotopes and specifically the C:N ratio provide information on past ciénega surface conditions (T. Minckley and others 2009) with lower C:N values indicating wetted conditions (fig. 4). Isotope data are particularly useful for understanding changes in pollen preservation and were instrumental to the identification of state changes in the paleoenvironmental record of San Bernardino Ciénega (T. Minckley and others 2009, 2011).

Reference State Models for Setting Restoration Goals in Desert Wetlands

Based on our observations of recent and past state changes in ciénegas, we propose a process-based ecohydrologic model of state transitions in ciénegas. This model integrates water balance, vegetation structure (above and below ground) and channel form as key variables that influence the trajectory of biogeomorphic change, and provides a framework for ciénega restoration and management. This model is comparable to state-and-transition models used to understand and manage arid-upland sites that have experienced heavy grazing pressure resulting in surface erosion, and encroachment of woody vegetation (Bestelmeyer and others 2003; Laycock 1991).

Depending on historic and present water availability, the potential natural states of ciénegas may be *dryland* or *wetland phases* (fig. 5a,b). Although these phases differ in the relative depth to groundwater and the persistence of surface waters, both states are characterized by surfaces with relatively homogeneous topography, high organic matter content and high resilience to erosion by floods. The current state of many ciénegas may be considered in a *degraded phase*, characterized by an active geomorphic surface, discrete channels, minimal surface water, and encroachment of woody vegetation, especially proximal to incised channel margins.

Throughputs for ciénega development are mainly hydrologic: groundwater (GW) through, surface flow (SF) in and out, and actual evapotranspiration (AE), which should be a net loss from the system

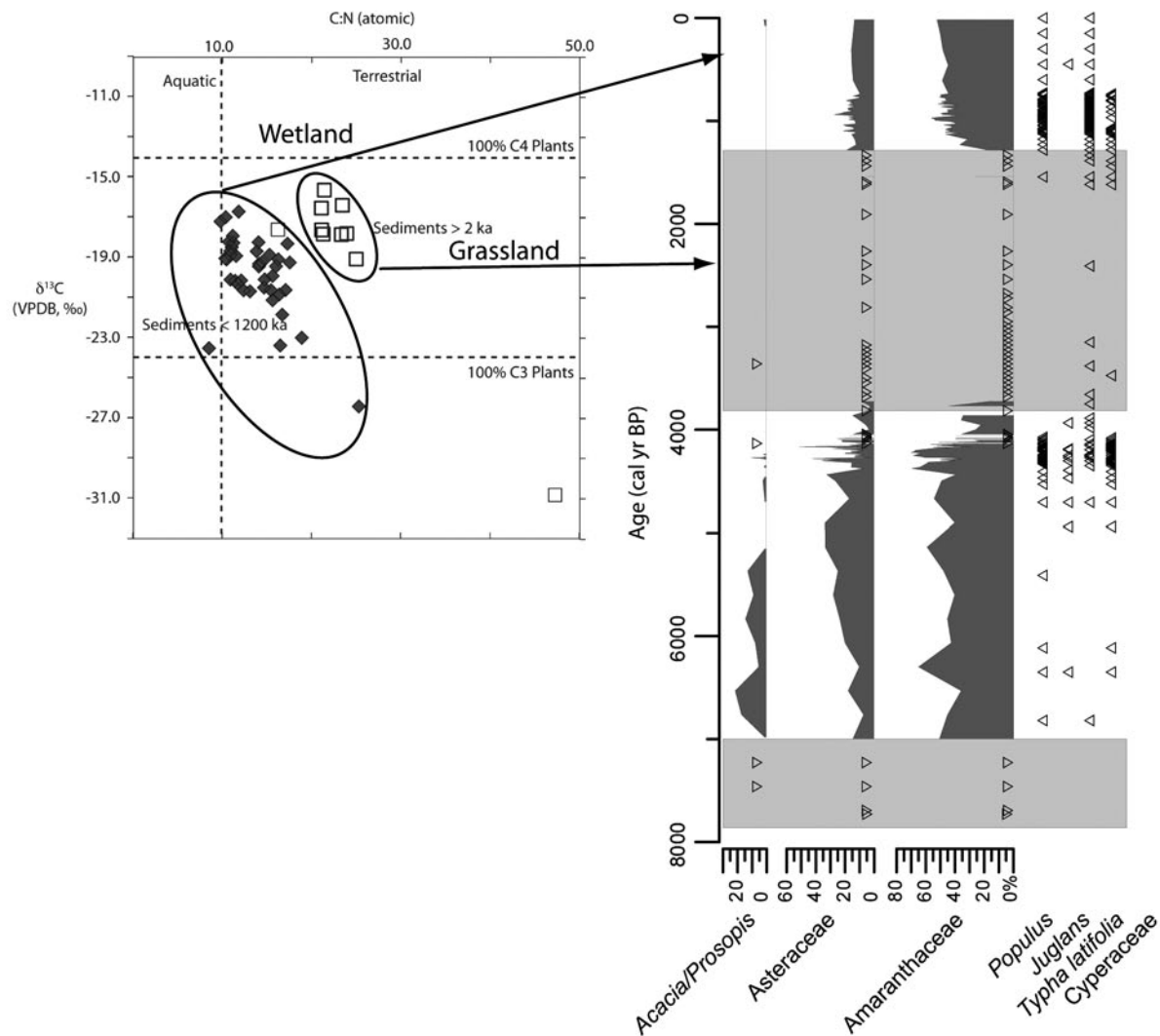


Figure 4—Scatterplot of C:N and $\delta^{13}\text{C}$ isotopic values for the past 4000 years next to the pollen data for San Bernardino Ciénega (T. Minckley and others 2011) showing the isotopic shift in sediments with poor pollen preservation, indicated by triangles in the first three columns, as compared to sediments with good pollen preservation, indicated by shaded pollen abundance curves.

as evaporative potential (PE) is high throughout the year (fig. 5a,b). However, upstream and upland sediment (SED) sources contribute to organic detritus, inorganic carbon, and sand, silts and clays (Heffernan and Fisher 2010; Heffernan and others 2008).

Dryland Phase—The dryland phase is the natural reference state that occurs when groundwater levels have likely decreased >25 cm below the surface for obligate wetland species (Stromberg and others 1996), allowing for grass and woody taxa encroachment (fig. 5b) (T. Minckley and others 2009). Presumably lowered groundwater tables result in no perennial surface flow, which decreases growth rates of the ciénega surface (Minckley and Brunelle 2007; T. Minckley and others 2011). Pollen preservation is reduced during the dryland phase because of the periodic exposure of deposited pollen grains to oxidizing conditions. Groundwater flow out of the system is lowered because of plant usage and evapotranspiration. Flood pulse attenuation occurs in the dryland phase, because surface flow is not channelized. Rather, broad ciénega surfaces disperse seasonal flood pulses into

sheet floods, preventing channelization. Sedimentary organic content is high during the dryland phase because of belowground competition for water resources. This competition further stabilizes the natural surface from degradation. Surface soil moisture is higher because of surface shading by woody and grassland taxa. AE is lower than PE in the dryland phase, but likely greater than in the degraded phase because of transpiration from vegetated surfaces and hydrologic lift associated with both the woody and grassland vegetation.

Wetland Phase—The wetland phase is the natural reference state that occurs when groundwater levels are at or above the vegetated surface resulting in standing water and saturated soils within and adjacent to a ciénega (fig. 5a). Most woody taxa are excluded from the ciénega surface because of the saturated soils. The combination of surface flow and groundwater flow through the system results in rapid and consistent aggradation of plant biomass and capture and burial of fine sediments from upstream sources (Heffernan and Fisher 2010). Pollen preservation is good during the wetland phase due to the

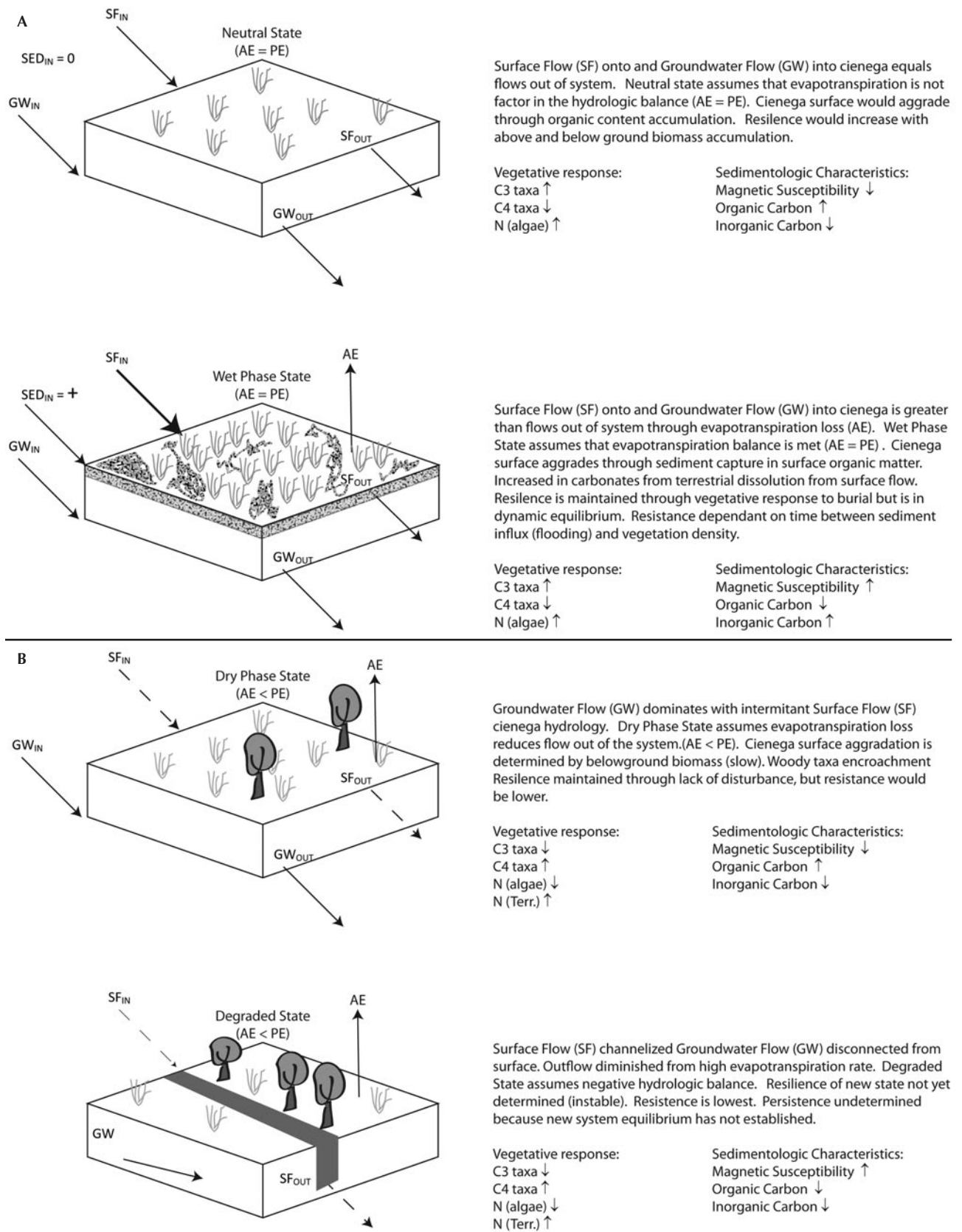


Figure 5—Conceptual models for natural ciénega phases based on hydrologic flux and vegetative responses. Model states form a basis for interpreting paleoenvironmental records from ciénega environments as well as provide management and restoration goals for present and future stable states. The neutral state forms a null hypothesis for comparing the three observed conditions for ciénegas in the American Desert.

anaerobic depositional environment. Flood pulse attenuation occurs in the wetland phase, because of surface characteristics and protection of soft sediments by the structure of dense above- and below-ground biomass (Heffernan 2008; Heffernan and others 2008). Seasonal flood pulses are slowed and sheet flooding across the entire surfaces results in increased inputs of sands, silts and clays (T. Minckley and others 2011). The moisture surplus results in a local balance of AE and PE.

Degraded Phase—Based on this conceptual model, the generic degraded state of ciénegas can be characterized as incised, having no surface water, poor groundwater connection for shallow rooted taxa, and experiencing woody taxa encroachment. Flood pulses are not attenuated in the degraded phase because of channelization concentrates flow and reduces sheet-flooding. AE is much lower than PE because of surface drying and low vegetation densities reduce near surface soil moistures (fig. 5b). The reconfiguration of the degraded state, relative to the natural states, may be extremely resilient to movement from this state, since flood power will be increased by concentrated flows within the channels and the incised channels maintain water levels well below the rooting zone of the adjacent terraces. Returning to one of the natural states, whether dryland or wetland, may be difficult based on present water availability, sediment flux, and vegetated surface-stability (DeBano and Schmidt 1990; Heffernan, 2008; Heffernan and others 2008), but is clearly possible as the state-change in Sycamore Canyon, Arizona, has demonstrated (Heffernan 2008). Natural re-establishment of ciénegas from the degraded state may occur primarily within recently formed (last 100 years) and much narrower active channels, while re-establishment of ciénegas to their former extents across entire valley channel widths may require active intervention that both redistributes surface flow and raises groundwater levels (i.e., check-dams placed within incised channels) (Heffernan 2008).

Management for the Paleoecological Perspective

State-changes in desert wetlands occur on multiple temporal scales; however, the current conditions of ciénegas in the American deserts are an artifact of the last 100-125 years of EuroAmerican settlement. Early research in changes in vegetation associated with lowered groundwater table (Bryan 1928) was the first indication of change in the region that favored deep rooted plant species. That changes in vegetation and hydrology are recent and upon the release of grazing pressure ciénegas can naturally reform (Heffernan 2008), suggests the natural resilience of these systems remains. Stromberg and others (2008) put forth that the responsiveness of vegetation in riparian corridors to changes in water availability reflected the constant renewal of the seed bank from both upland and riparian taxa. The constant double-sourcing of the seed bank would provide a mechanism for observed rapid vegetation changes in ciénega systems or state-changes over the long-term in both modern and paleoenvironmental studies. The rapid response may be based simply on changing precipitation timing and amount, and the consequent groundwater recharge, as the depth to water table is likely the ultimate control on natural ciénega states (Stromberg and others 1996).

Setting restoration targets for the management of ciénegas requires using the best information available. Unfortunately, reference conditions are poorly known as the degradation of ciénegas in the American Deserts was a post-hoc observation of a region changed by settlement, grazing, and land-use (Bryan 1925, 1928; Leopold 1949; Turner 2007; Turner and others 2003). The paleoecological record does provide insight into how ciénegas behaved under different climate regimes

providing achievable restoration and management targets, based on current climate conditions and water availability, both natural and legal based on water rights. Based on the hydrologic flow and evidence of two potential natural states, ciénega management and restoration can target the dryland or wetland state as equally viable and within the natural range of variability for these environments (Millar and Woolfenden 1999).

Management could be focused on restoration of surface stability as either a grassland or wetland phase as a first order goal. In either state, the potential ecosystem services of ciénegas and the potential for natural state changes are restored. Passive management could follow allowing the natural seeding of the system to adjust the vegetation composition based on short and long-term climate variability (Stromberg and others 2008). Ciénegas have the potential to represent a great success story in conservation given that the degradation of these systems is relatively recent and we observe a great resilience in ciénega vegetation released from disturbance pressure (Garnett and Lindenmayer 2011; Heffernan and Fisher 2012; Heffernan 2008; Heffernan and others 2008). Optimistically, our expanding understanding of the mechanisms controlling ciénega form and function in the Madrean Archipelago can serve as a model for management of these resources in arid regions around the world (T. Minckley and others, *in review*).

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Northern Jaguar Reserve

When Will Female Jaguars Cross the Border? Socio-Demographics of the Northern Jaguar

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Abstract—Conservation biologists, NGOs, and the USFWS have established a goal of returning a viable population of jaguars into the United States. The source population for this recovery will come from Sonora, Mexico, the closest sub-population of the species. To maintain a viable population there must be females and an active corridor that allows passage of jaguars between Sonora, Arizona, and New Mexico. While considerable attention has been paid to the corridor, little attention has been paid to the potential rate of expansion of the existing population and the importance of female jaguars to dispersal. This paper's purpose is to highlight what is known of the socio-demographics of northern jaguars, the differing role that females play in dispersal, the possible return-times for females to the U.S. Sky Islands, as well as conservation priorities.

Introduction

To the best of our knowledge, jaguars (*Panthera onca*), in the 1800s, lived year-round in some areas of Arizona and New Mexico. About 60 sightings have been more or less confirmed in Arizona and New Mexico in the twentieth century (Brown and Lopez-Gonzalez 2001). Most recently (between 1996 and 2012), five male jaguars have been photographed in the Animas, Peloncillos, Whetstones, Atascosas and Baboquivari Sky Islands of the United States. Dispersal male jaguars have been known to range widely; by analogy with other large cats, hundreds of miles per year (Brown and Lopez-Gonzalez 2001; Hoogesteijn and Mondolfi 1992).

No female jaguars have been recorded in the United States since 1963. The last female with a cub was shot in 1910 in Cheylon Canyon, Arizona. The nearest female jaguar to the U.S. border was shot south of Moctezuma, Sonora in 1998. A female with cub has been recorded by camera-traps on the Northern Jaguar Reserve (about 125 miles from the border) in 2011. As opposed to adult males, adult female jaguars are not known to range widely (Brown and Lopez-Gonzalez 2001; Hoogesteijn and Momdolfi 1992).

Jaguar males have large home ranges that may contain smaller female home ranges (Hoogesteijn 1992; fig. 1). In addition, there appear to be nomadic males that are dispersing and wandering and may not have any settled home range. The dispersal of female jaguars can be visualized as the creation of home ranges within the boundaries of one or two male home ranges (fig. 1).

A 1,100 square mile area in Sonora (Lopez-Gonzalez and others 2000, Lopez-Gonzalez and Brown 2002) has been delineated as the area with the highest jaguar numbers and the most likely source area for U.S. jaguars. The population of jaguars in this and adjacent areas has been estimated at 80 to 120. Two general "corridors" that may be

used by Sonoran jaguars to return to the U.S. Sky Island mountains have been suggested (fig. 2; Valera-Aguilar and others, abstract, this volume). However, the rates of population expansion and dispersal through these corridors are unknown. This paper presents the social and demographic factors that may contribute to population expansion and dispersal, including very simple math-based scenarios to provide various timeframes for return of adult female jaguars to the United States. The results of these scenarios pose two conservation biology questions: Would it be better to re-introduce female(s) to the potential jaguar habitat in the United States (pro-active restoration) or wait for dispersing females to reach the United States (passive restoration)? What does knowing probable timeframes contribute to the decisions necessary for return of a U.S. reproductive population?

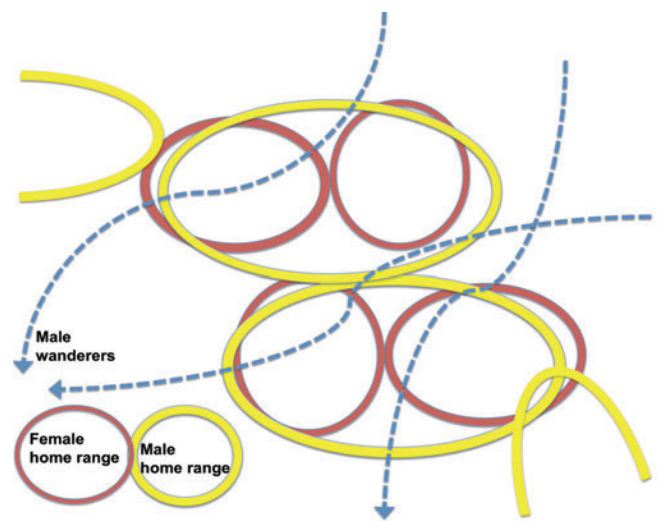


Figure 1— Home ranges of jaguars (based on Hoogesteijn and Mondolfi 1992). The yellow circles are male home ranges; the red circles are female home ranges; and the dotted blue lines are male wanderers without home ranges.

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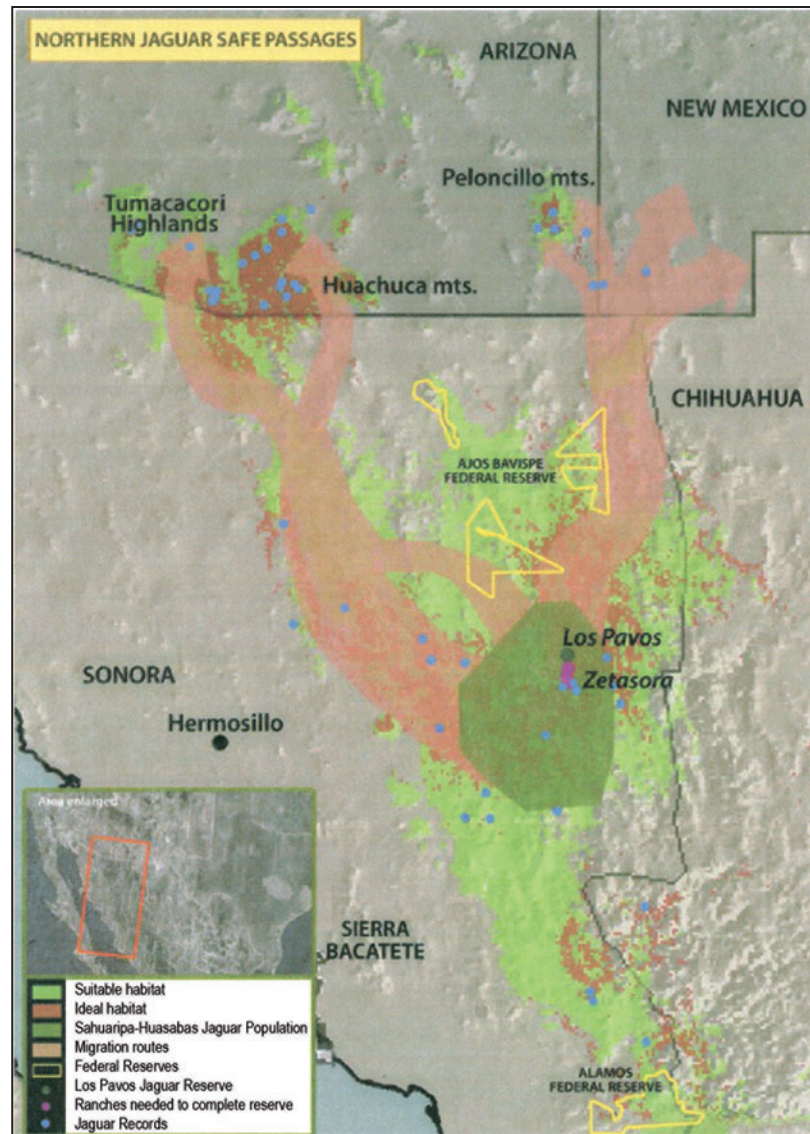


Figure 2—Locations of Northern Jaguar Reserve, core area of northern jaguar population (green polygon) and probable dispersal corridors to the Sky Islands in the United States. Blue dots are recent jaguar sightings.

Methods

To estimate the probable minimum times for return of female jaguars, I first assembled what is known and not known of their life history phenomena in their northern range or, if unavailable, for southern jaguars in the most open or arid habitats (table 1). Southern jaguars, especially those living in tropical humid forests (as opposed to thornscrub, pinyon-juniper woodland, riparian and montane biotic communities), have differing life-history phenomena (Hoogsteijn and Mondolfi 1992). Life-history phenomena include (1) sex ratio at birth, (2) the number of cubs (litter size), (3) age of first reproduction, (4) average lifespan, (5) number of years between litters, and (6) pre-reproductive mortality of cubs.

In addition, I assembled what is known about home range size and dispersal (age at dispersal, overlap with mother's home range, residency

time in home range and direction of dispersal; table 2). For each data point (tables 1 and 2), the degree of reliability is noted. These two sets of admittedly incomplete data were combined into a simple iterative model to estimate the miles per generation that a female might move north (table 3). "Optimistic" and "conservative" scenarios were used to frame the probable number of miles per generation. The numbers of years for return was calculated from the closest female sightings to the border to the nearest U.S. Sky Island in which males have been seen.

The scenarios include many assumptions that require further refinement: (1) more accurate life-history phenomena and dispersal data; (2) the verification of the postulated corridors and pathways; (3) further understandings of directional choice and female home range use; and (4) the use of a circle to define home range shape.

Table 1— Life-history phenomena of female jaguars (data from Brown and Lopez-Gonzalez 2001, Hoogesteijn 1992).

Life-history phenomena	Data	Reliability and notes
Sex ratio of litter	Unknown	
Number in litter	Average: 2 Range: 1-4	One NJR litter of one. Extrapolated from other populations.
Pre-reproductive mortality	Unknown	Expert opinion estimates 3–6 cubs reach adulthood per generation.
Age at first reproduction	2.5–3 years	Extrapolated from southern jaguar.
Time between litters	3 years	Well documented
Lifespan (years)	Average: unknown From fieldwork: 10–13 From zoos: 20-25	No northern jaguar data. Reproductive lifespan maybe 7–10 years in field.
Number of cubs per lifespan (cpl)	Litter of one cub every 3 years = 3–4 cpl Litter of two cubs every 3 years = 6–9 cpl	If sex ratio is 1:1, the number of female cpl ranges from 2–5.

Table 2— Dispersal phenomena of female northern jaguars (data from Brown 2001; Hoogesteijn 1992; Gutierrez-Gonzalez and others, this volume).

Dispersal phenomena	Data	Reliability and notes
Home range size	Venezuela: 10-15 sq mi Jalisco, MX: 10-25 sq mi NJR: 25-37 sq mi	NJR has limited data.
Age at dispersal	1–1.5 years	Well documented.
Overlap with mother's home range	Range: Adjacent to 85% Venezuela: 17–40%	No NJR or northern jaguar data.
Residency time in home range	South America: 6 years plus?	NJR: very limited data.

Table 3— Scenarios for return of female jaguars to the United States.^a

Scenario	A. Size of new home range needed by daughter	B. Daughter's movement outward from mother's home range ^b	C. Years to disperse 100 miles and 125 miles when daughters move outward every three years ^c
Daughter does not share mother's home range but settles adjacent to it	25 sq mi	5.6 miles	54 to 67 years
	37 sq mi	6.8	44 to 55
Daughter shares 40% of mother's home range	15 sq mi	4.4 miles	68 to 85 years
	22 sq mi	5.2	58 to 72
Daughter shares 85% of mother's home range	2 sq mi	1.6 miles	188 to 243 years
	6 sq mi	2.8	107 to 134

^aAll calculations available on Excel by request from information@northernjaguarproject.org.

^bDistance outward = diameter of added home range = 2 X square root of area in column A/π.

^cReturn times = 100 or 125 miles X 3 years/miles in column B.

Results

To the best of my knowledge, table 1 summarizes life-history knowledge and table 2 presents information on dispersal of female jaguars. Since nothing is known of sex ratios at birth, pre-reproductive mortality, or how females chose which direction to extend their home ranges, these numbers are subject to significant revision. A young female could theoretically create her home range in any direction. As few as 25% of all daughters might extend the female population's range in a northward direction.

Other numbers may also be significantly altered as more is known of the impact of the northern jaguar's arid landscape on home range size and shape and litter size. Jaguar home ranges change widely with season, the location and number of roads, prey size, and the first months of raising cubs (Hoogesteijn and Mondolfi 1992). The quantitative impacts of prey density, human settlements and riparian habitat on northern jaguar home range shape and size have just begun to be investigated. Two "wildcards" exist: a female could be discovered much closer to the border or a female might (although never reported) wander with a male a much greater distance.

Scenarios

For the purposes of these scenarios, it is important to emphasize that young females do not appear to move great distances from their natal home range. There is some evidence that a female cub may be given perhaps 17 to 40% of their mother's home range and, should the mother die, may take over 75-85% of her home range (Hoogesteijn and Mondolfi 1992). It is not known how mother jaguars divide up their home ranges when they have two female cubs at the same time or in sequential litters.

A northern jaguar female's home range size will be considered 25 square miles (a diameter of approximately 5.6 miles) to 37 square miles (a diameter of approximately 6.8 miles). This is about half the known home range size of a male on the NJR (Gomez-Gutierrez and others, abstract, this volume) and about the size reported for several more open landscapes in South America (table 2). The scenarios assume that each mother has a new daughter every 3 years, which is the spacing between a mother's pregnancy and the first litter by the daughter.

Three scenarios (table 3) for the smallest and largest home ranges were used to frame the number of years for female jaguars to return to the U.S. Sky Islands. The first assumed that the daughter's home range did not overlap with her mother's but was adjacent to it. The second assumed a 40% overlap. The third assumed an 85% overlap (the mother dies). All scenarios make the optimistic assumptions that home ranges moved north and every litter included at least one female cub. They all assume the home range's shape is a circle.

When the mother and daughter home ranges are adjacent to each other (do not overlap), a daughter moves north 5.6 to 6.8 miles every 3 years. In the more conservative scenario a dispersing subadult female shares 40% of her home range with her mother and the daughter moves north 4.4 to 5.2 miles every 3 years. The most conservative assumes an 85% overlap with a northward crawl of 1.6 to 2.8 miles every 3 years.

Since 1990, there have been six verified sightings of females with a cub in northern Sonora (Brown and Lopez-Gonzalez 2001).

The direct, straight-line distances to the U.S. border Sky Islands for females have ranged from about 100 to about 125 miles and could easily be twice as large given the rugged terrain. Given all the assumptions, it may be reasonable to speculate that the fastest female inter-generational lineage might return to the U.S. Sky Islands in 45 to 70 years; conservatively 60 to 85; and if many of our assumptions are too optimistic, from 100 to 250 years (table 3).

Discussion

From these scenarios, it is clear that, if passive restoration is preferred, jaguar conservation in the U.S. Sky Islands will require a long-range view, and U.S. lands and prey densities of deer, javelin, cattle, and smaller prey may need to be protected for a half-century or more before a female appears. Although not studied in any detail, the pathways north to the U.S. Sky Islands may become more difficult over the next 50 to 150 years as borderland habitats become increasingly fragmented, settled by humans, and the border fence "permanently" blocks some potential routes. In addition, the border highway in Sonora will be widened within the next few years.

A bi-national discussion of how conservation funding should be spent most effectively is necessary. Should funding be spent in Sonora to improve dispersal from the core zone in *all* directions or spent primarily on helping northern jaguar females move north? Which is the more effective way to raise the population from the present 40 or 50 female jaguars to a more viable population size? Should funding preferentially address land protection within the "corridor" to the south from the Northern Jaguar Reserve to Sinaloa, which restocks the small northern population and may provide genetic diversity? Should active restoration by transferring females north into the U.S. Sky Islands be attempted?

The scenarios will hopefully improve in accuracy in the next decade or two. Perhaps a female will be photographed much closer to the border. The scenarios provide a framework for decision-making that elevates the importance of females and rates of dispersal in addressing conservation issues.

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Bird Ecology and Conservation on the Northern Jaguar Reserve: Recent Lessons

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Abstract—*The Northern Jaguar Reserve is in the western foothills of the Sierra Madre Occidental and in a broad transition zone between Nearctic and Neotropical faunal realms. We have assessed the distribution and abundance of birds across all four seasons in foothills thornscrub, oak woodland, and adjacent riparian areas, and discuss issues relevant to conservation and management. Since 2007, we have observed 205 species of birds including 131 that are Neotropical migrants, 104 that likely breed on the reserve, and 35 species of binational conservation concern. Observations suggest this 20,140-ha reserve has significant conservation value to migratory birds that traverse an inland migratory flyway that includes the Sky Islands; breeding species that use foothills thornscrub, oak woodland, and riparian woodlands along the Rio Aros and its tributaries; and numerous species and populations of significant conservation value. Existing conservation efforts include land purchase, cattle exclusion, invasive plant removal, and habitat restoration on both neighboring private ranches and the reserve.*

Background

The 20,140 hectare Northern Jaguar Reserve (NJR) sits at the northwestern foothills of the Sierra Madre Occidental, the “mainland” of mountains south of the Madrean Archipelago. It lies in the transition zone between the Nearctic/Neotropical faunal areas of the planet and between the coastal and high sierra montane regions of Sonora. The nearest Sky Islands that support pine-oak woodland are the Sierra la Madera and the Sierra Bacadehuachi.

The NJR is surrounded on three sides by the deep canyons of the Ríos Aros and Yaqui. This difficult-to-access region is among the largest and least fragmented regions in northwest Mexico and supports a population of jaguars (*Panthera onca*) (Brown and Lopez-Gonzalez 2001), which became the central focus for creating this private reserve. Naturalia (a Mexican conservation organization) owns the reserve and the Northern Jaguar Project and Naturalia manage it.

Before 2007, few ornithologists had visited this region of foothills thornscrub, oak woodland and shrubland, and riparian woodlands in east-central Sonora. Thus, there were few data on the occurrence, abundance, breeding and residency status of birds in the interior foothills of Sonora on the western edge of the Sierra Madre and little information to guide conservation and habitat management efforts. Between 2007 and 2011, we surveyed birds on and around the NJR and estimated the status and seasonal abundance of all bird species. This article discusses lessons we have learned about birds and their conservation implications. Estimates of seasonal abundance and status

of birds will be presented in a companion paper (Flesch and Warshall, in preparation).

Methods

Detailed information on sampling methods and locations are described in Flesch (2007) and are not repeated here. To estimate bird abundance, we used distance sampling along eight line transects surveyed during each of four seasons over 1-2 years; seasons were defined by the breeding and migratory phenology of local species. To assess breeding, migratory and residency status, we observed bird behavior, conducted nest searches and used mist-netting and incidental observations from this and other efforts across the region.

Lesson 1: An Inland Migratory Corridor for Birds

Data gathered during our efforts on the NJR suggest the importance of an inland (vs. coastal) flyway for many types of Neotropical migratory birds in Sonora. We observed 78 species of passage migrants, which represented 38% of all 205 species observed in the region. In addition to passage migrants that often move long distances between their winter and summer ranges, the reserve supports some species of short-range migrants including many that likely originate in the southwestern United States. Although determining the origin of these short-range migrants is difficult without extensive banding efforts or molecular techniques, probable short-range migrants that occur in the NJR include Turkey Vulture, Black Vulture, Common Blackhawk, Bald Eagle, Elegant Trogon, Costa’s Hummingbird, Lucy’s Warbler, Buff-collared Nightjar, Inca Dove, and Common Ground-Dove.

During winter, some short-distance migrants that occur on the NJR are elevational migrants that likely breed to the north and east in montane habitats of the Sky Islands and adjacent Sierra Madre.

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

These species include: White-eared Hummingbird, Buff-breasted Flycatcher, Tufted Flycatcher, Greater Pewee, Slate-throated Redstart, and Brown-backed Solitaire. At this relatively northerly latitude, Tufted Flycatcher and Slate-throated Redstart that breed locally to the east and southeast may migrate downslope, north and west into the NJR to winter.

Finally, there are migratory species of more tropical affinity many of which do not occur as far north as the Sky Islands of the United States, but may breed in the Mexican Sky Islands. They breed or are suspected to breed on the NJR reserve at or near the northern margins of their range and most migrate south in winter. These species may be short-distance migrants (Military Macaw, White-tipped Dove, White-striped Woodcreeper, Rose-throated Becard, Thick-billed Kingbird, Sinaloa Wren, Blue Mockingbird, Rufous-capped Warbler, Fan-tailed Warbler, and Five-striped Sparrow) or long-distance (Sulphur-bellied Flycatcher, Yellow-green Vireo).

The seasonal bird assemblages are additionally complex because different sub-populations of the same species may be permanent residents or dwell on reserve only as breeders in summer, over-winterers, or passage migrants. At times, it is not certain which sub-population (the migratory, resident) is present, although for some species such as Lucy’s Warbler mid-summer passage migrants often arrive several weeks after most spring breeders have departed. Without additional study and wider spatial coverage, the exact origin of migrants remains unknown.

In summary, the reserve is the first area in the foothills of the Sierra Madre Occidental in Sonora to be surveyed intensively for birds. Among seasons, bird populations include species that are Neotropical passage migrants, Neotropical summer breeders, elevational migrants that breed in Madrean environments in nearby mountains, permanent residents, and short-range over wintering migrants (table 1). Differences in density among seasons indicate large influxes of migratory species dominated by flycatchers, vireos, and warblers during spring and again during late summer and fall that together represented large proportions of total bird abundance compared to winter and summer residents (Flesch and Warshall, in preparation). About 60% (n = 131) of bird species have been categorized as Neotropical migrants by the U.S. Fish and Wildlife Service. When elevational migrants and subtropical summer breeders are considered, about 75% of bird species observed had migratory habits.

These fall and spring bird assemblages reveal the great complexity (table 1) that occurs in the Neotropical/Nearctic transition zone. They pose as yet-to-be-researched conservation challenges to understanding

Sky Island bird assemblages. For instance, does the reserve region represent a weak or strong “link” in the annual cycle of one or more populations of birds? Which habitat features and resources promote high rates of winter and summer resident survival and/or population growth? What are the high-quality foraging plant associations for passage migrants? Do the same species use the flyway in both spring and fall? Do migratory flyways shift away from the coastal plain to the foothills and mountains in fall? What species and habitats are most critical for conservation? To address some of these questions, we are now studying over-winter survival of migratory populations and continuing to monitoring abundance across space and time.

The potential importance of an inland corridor for migrants has changed conservation thinking about land purchase and habitat protection in inland Sonora. How many “stepping stones” are protected? How wide is the flyway? The closest reserves in the inland corridor to the NJR are the state reserve (Cerro Las Conchas/Arivechi) and the Ajos-Bavispe federal reserve, which includes the nearby Sierra la Madera and upper Rio Bavispe, and the more distance Sierra los Ajos, Buenas Aires and Purica. The NJR is the only protected area where logging, land clearing, and cattle grazing cannot occur. A proposed Presidential decree would also protect it from mining. In addition to the reserve, the Sanctuario Aquila Calva (that covers part of the NJR) and Sierra Huerfana have been proposed (Burquez and Martínez-Yrizar 2006). Elsewhere, habitat protection in east-central Sonora is de facto in origin and driven largely by the inaccessibility of these lands to people and livestock.

Lesson 2: The Importance of Foothills Thornscurb and other Plant Associations

Vegetation in the uplands of the NJR is composed predominantly of foothills thornscurb (FT), which is drought deciduous, in leaf during and after the summer monsoon season from July through September, and defoliated during much of the winter and spring (Brown and Lowe 1980). The northern edge of foothills thornscurb occurs less than 50 km to the north and 100 km to the northwest, yet important dominants such as *Lysiloma divaricatum* and *L. watsonii*, *Bursera fagaroides*, and *Ceiba acuminata* occur at scattered localities as far north as the Baboquiviri and Rincon Mountains (Brown and Lowe 1980; Turner and others 1995). Our observations suggest that FT is an important and undervalued biotic community for migratory and breeding birds. The NJR is the only reserve in Mexico that protects extensive areas of FT.

Table 1—Seasonal bird assemblages on Northern Jaguar Reserve.

Spring	Summer	Fall	Winter
Residents	Residents	Residents	Residents (some may move locally)
Long-distance passage migrants from south	Southbound early “fall” passage migrants from north	Long-distance passage migrants from north	Overwintering migrants “long-distance” migrants from north
Early migrant breeders from south	Molt-migrants from the north	Short-distance passage migrants from north	Overwintering elevational migrants
Wintering species yet to depart for more northern breeding grounds	Summer breeders (some subtropical migrants; a few Neotrop migrants).	Over-wintering migrants from north	Over-wintering short-distance migrants from north
	Second breeding species that already bred further north?	Molt-migrants from north	

Foothills thornscrub is a diverse vegetation community with various discrete plant associations that occur at varying elevations and soils (Burgess 2009). Given this diversity, some plant associations and plant species within FT and their value to specific species and foraging guilds need to be defined so that this information can be

applied to developing more efficient conservation plans and priorities. Based on our knowledge of the natural history and ecology of birds and their habitats in this region, we began, for the first time, to define these various plant associations and assess their potential value to birds (table 2). For example, the tree ocotillo/tree morning

Table 2—Plant Communities and Plant Associations of the Northern Jaguar Reserve (based on Burgess 2009; Flesch and Warshall unpublished paper) mentioned in text.

Plant community and associations	Dominant species	Structure, habitat	Value to birds
Foothills Thornscrub (FT) on Hillslopes	<i>Bursera</i> , <i>Lysiloma</i> , <i>Ipomoea arborescens</i> , <i>Fouquieria macdougalii</i> ,	Trees, shrubs and cacti 3-10m tall; often on colluvial, volcanic soils.	Early breeding hummingbirds, foliage gleaners, aerial insectivores; cavity nesters; shrub specialists.
FT - Mesic Phase	<i>Lysiloma divaricatum</i> , <i>Ceiba</i>	8-12m tall, sheltered areas that promote high soil moisture.	Foliage gleaners, aerial insectivores, foragers. Possibly Military Macaw. Tall FT specialists.
FT - Rocky Canyon Bottoms	<i>Lysiloma</i> , <i>Ceiba</i> , <i>Sapindus</i> , <i>Havardia</i> , palms	Taller xeroriparian: woodland, often mixed with tropical deciduous forest species, oaks, riparian species	Monsoonal foliage gleaners and migrants, aerial foragers, bark gleaners, tall tree and cavity nesters
FT - Open arid scrub	<i>Bursera laxiflora</i> , <i>Stenocercus thurberi</i> , <i>F. splendens</i> , dense microphyllous shrubs	Xeric phase FT, short 1-3 m canopy, patchy depending on substrate	Scrub and desertscrub specialists, raptors, Costa's Hummingbird
FT – Hop bush pre-montane shrub	<i>Dodonaea viscosa</i> mixed with shrubs	2-4 m tall, often in homogenous stands with interspersed patches of FT shrubs. Volcanic and hydrothermal substrates.	Shrub specialists, ground foragers
FT - Upper elevation pre-montane scrub	<i>Yucca grandiflora</i> , <i>Sabal uresana</i> , <i>Dasyllirion</i> , <i>Lysiloma watsoni</i> , grasses	Tuft plants and bunchgrasses, scattered patches of short thornscrub often frost damaged	Scott's Oriole, Rufous-crowned Sparrow, grassland species, raptors, wintering sparrows
Oak-savanna mosaic	<i>Quercus chihuahuensis</i> , <i>Quercus toumeyi</i> , <i>L. watsoni</i> , <i>I. arborescens</i>	At elevations mostly above 900 m. Open short woodland or scrub with FT vegetation and grassy mosaic. Often frost damaged	Scott's Oriole, Rufous-crowned and Rusty Sparrows, Blue-gray Gnatcatcher. Grassland species, raptors, wintering sparrows
FT on limestone or other rocky hillsides	<i>Tecoma stans</i> , <i>Plumeria rubra</i> , <i>Agave sp.</i>	Localized shrubland on rocky outcrops and canyon walls	Hummingbirds, orioles.
Rio Aros riparian woodland and forest	<i>Salix bonplandiana</i> , <i>S. gooddingii</i> , <i>Sapindus</i> on floodplain	Tall but often patchy galleries of willow; 8-20 m tall along the river	Foliage gleaners, aerial insectivores, bark gleaners. Bald Eagle, other raptors.
Alluvial terrace xeroriparian and FT Xeroriparian	<i>Prosopis velutina</i> , <i>Havardia mexicana</i> , <i>Acacia occidentalis</i> , palms, with understory of <i>Celtis pallida</i> and other shrubs	Woodlands of tall microphyllous species; 4-20 m tall on deep sandy soils on higher terraces above rivers and main terraces along major tributaries	Foliage gleaners, aerial insectivores; nesting raptors (Common Blackhawk). Lucy's Warbler. Brown-backed Solitaire, Orioles.
Mesic pre-montane riparian woodland and Oak-Palm riparian woodland	<i>L. watsonii</i> , <i>Q. tuberculata</i> , palms, <i>Havardia</i> ; FT and Tropical Deciduous Forest riparian shrubs	Deep soil, north-facing canyons with semi-perennial water. Woodlands 10-15 m tall	Summer breeders, foliage and bark gleaners, aerial insectivores, wintering elevational migrants. Violet-crowned Hummingbird, White-striped Woodcreeper, Sulphur-bellied Flycatcher, Rufous-capped and Fan-tailed Warbler, Black-vented Oriole.
Sycamore riparian gallery forest	<i>Platanus</i> , <i>Q. tuberculata</i> , <i>Cephalanthus</i> , <i>L. watsoni</i> , palm, <i>Sideroxylon persimile</i>	Deep soils, often north-facing canyons with perennial water; woodlands 10-20 m tall; physiognomic diversity, complex structure	Summer breeders, foliage gleaners, aerial insectivores, bark gleaners, wintering elevational migrants Common Black-Hawk, Rufous-capped and Fan-tailed Warblers. Hooded Oriole.
Oak woodland	<i>Q. chihuahuensis</i> , <i>Q. tuberculata</i> , <i>Q. toumeyi</i> , <i>Q. albocincta</i>	Usually 900m or higher on north-facing slopes, ridges, canyons	Winter resident and migratory granivores. Hepatic tanager.

glory/Justicia association (*Fouquieria macdougalii* // *Ipomoea arborescens* // *Justicia* sp.) flowers in late winter and provides valuable nectar resources to migratory hummingbirds and orioles. Monsoon rains provide hillslope FT, open woodland FT, xeroriparian FT, mesic phase and rocky-bottom FT with abundant foliage and insects for foliage gleaners and aerial foragers. *Guacima*, *Lysiloma*, *Bursera*, *Cebia* and the fig species *Ficus pertusa* and *F. insipida* provide fruit for Military Macaws and other frugivores.

This new attention to FT has brought up new conservation and management questions. They include how fire (both natural and human-caused), freezing temperatures, and drought affect needs of various species of birds; how over-grazing and over-abundant native and non-native invasive plants affect bird species composition and density, and how harvesting of wild agaves affect populations of nectivores. As seasonal utilization of the plant associations and plant species that occur within FT becomes better known, restoration of previously grazed or cleared lands can be more intelligently designed. Thus far NJP and Naturalia have focused on more mesic riparian sites that support woodlands.

Lesson 3: Importance of the Rio Aros and Riparian Vegetation

The reserve includes 37 km of waterfront along the Aros River, one of the few remaining large free-flowing rivers in Mexico. NJR and a federal reserve in its headwaters (Tutuaca) are the only areas with protected status along the river (Burguez and Martínez-Yrizar 2006). The Rio Aros on and around the NJR supports among the highest densities of breeding Common Black-Hawks in northern Mexico (Rodríguez-Estrella 1990; O'Brien and others 2006), the southernmost breeding population of Bald Eagle in the interior of Mexico, the northernmost breeding population of Military Macaw, and populations of many other species at the northern or southern end of their breeding and wintering ranges (Flesch and Warshall in preparation). One obvious lesson is that the vast lowland corridor formed by the Rio Aros, Yaqui, and Bavispe provides valuable habitat for birds that require riparian woodlands, tall trees, beachfront and riparian shrub communities, and that consume aquatic prey (table 2).

Efforts to protect habitat on and around the NJR have included land purchase, especially valuable riparian habitats; fencing of alluvial terraces and shorelines from cattle in partnership with neighboring ranches; establishing a plant nursery to support restoration work; partnerships with Mexican natural resource agencies and neighboring landowners to restore riparian vegetation including sycamore woodlands, and conversion of cattle tanks into more wildlife-friendly ponds. The goal of these efforts is in part to augment habitat for birds such as Bell's Vireo, Yellow and Wilson's Warblers, and Yellow-breasted Chat that are associated with or obligated to riparian habitats (Skagen 2005). On a river basin scale, conservation objectives include educating the public, collecting data to help prevent the construction of a dam on the Rio Aros, and limiting potential toxic chemical pollution into the river from mining.

Lesson 4: Birds of Conservation Concern

Birds of concern are often classified at local, regional and continental scales to address variable threats to different populations among species and subspecies (Shuford and Gardali 2008). We identified 34 birds on the NJR (table 3) that are listed as birds of concern by USFWS, National Audubon Society, Partners in Flight and the Mexican Federal

Table 3—Birds of Concern on the Northern Jaguar Reserve.

Concern	Species
Continental assessments of birds of concern	Costas and Broad-tailed Hummingbirds, Elegant Trogon, Olive-sided Flycatcher, Bells and Warbling Vireos, Varied and Painted Buntings, Wilsons and Lucy Warblers, Brewer's Sparrow, Swainson's Hawk and Western and Summer Tanagers
Bird populations that are in steep decline (greater than 50% decline in the last 50 years)	Yellow-billed Cuckoo, Rufous Hummingbird, Rock Wren, Wilson's Warbler, Brewer's Sparrow and Grasshopper Sparrow
Mexican federal agency birds-at-risk	Sharp-shined, Cooper's, Swainson's, Zone-tail Hawks, Common Blackhawk, Bald Eagle, Peregrine Falcon, Military Macaw.
Potential molt migrants	<i>Western Wood-Pewee</i> , <i>Hammond's Flycatcher</i> , <i>Dusky Flycatcher</i> , Gray Flycatcher , <i>Pacific-slope Flycatcher</i> , Cordilleran Flycatcher , <i>Ash-throated Flycatcher</i> , <i>Western Kingbird</i> , Bell's Vireo , <i>Plumbeous Vireo</i> , <i>Cassin's Vireo</i> , Black-throated Gray Warbler , <i>Townsend's Warbler</i> , <i>Wilson's Warbler</i> , <i>Hepatic Tanager</i> , <i>Summer Tanager</i> , Green-tailed Towhee , <i>Chipping Sparrow</i> , <i>Clay-colored Sparrow</i> , Brewer's Sparrow , <i>Lark Sparrow</i> , Grasshopper Sparrow , <i>Black-headed Grosbeak</i> , <i>Hooded Oriole</i> , and <i>Lesser Goldfinch</i> .
Bold: Priority I species for Partners in Flight <i>Italic:</i> Also Priority II or III species of Partners In Flight	
High priority Neotropical migratory birds of concern for overwintering survival (DeSante and others 2009)	<i>Willow Flycatcher</i> (endangered, rare migrant); <i>Dusky Flycatcher</i> (frequent migrant, uncommon winter resident); <i>Warbling Vireo</i> and <i>Wilson's Warbler</i> (common migrants); and <i>Painted Bunting</i> (uncommon fall migrant).

Government (Berlanga and others 2010; Partners in Flight 2006). These species include 28 migrants as well as subtropical breeders.

The NJR also supports molt migrants. Habitat protection for molt-migrants is a new and potentially important conservation objective. Many birds that breed in western North America leave their breeding grounds in July and August and migrate to the "Mexican monsoon region" where they use seasonally abundant resources to molt and refuel before continuing to their wintering grounds. Because molting is among the most energy-demanding events in the annual cycle of a bird, maintenance of high quality stopover habitat for these species is crucial to their persistence (Pyle 2009). Little was known of this phenomenon in the inland foothills of Sonora until NJP's recent studies.

Of 34 species of likely molt-migrants in the broader region (Pyle 2009), NJP has caught, measured, and banded 14 (40%) in 2011 (Hanunselka, personal communication; table 3). Nine of these species (table 3) are classified as Birds of Conservation Concern or Priority I species by Partners in Flight (2006). In addition to confirmed molt-migrants (Hooded Orioles, Black-headed Grosbeaks, and Summer Tanagers which all showed clear molting), we have also recorded eight "candidate" species of molt migrants (including two common passage migrants, Warbling Vireo and Wilson's Warbler).

These birds-of-concern lists, State of Sonora, Mexican and binational conservation initiatives as well as strategic surveys and monitoring on the NJR are crucial conservation tools to aid in recovery and forestall further listings.

Table 4—Birds mentioned in text.

Common name	Scientific name
Black Vulture	<i>Coragyps atratus</i>
Turkey Vulture	<i>Cathartes aura</i>
Common Black-Hawk	<i>Buteogallus anthracinus</i>
Bald Eagle	<i>Haliaeetus leucocephalus</i>
Sharp-shinned Hawk	<i>Accipiter striatus</i>
Cooper's Hawk	<i>Accipiter cooperii</i>
Swainson's Hawk	<i>Buteo swainsoni</i>
Zone-tailed Hawk	<i>Buteo albonotatus</i>
Peregrine Falcon	<i>Falco peregrinus</i>
Common Ground-Dove	<i>Columbina passerina</i>
Military Macaw	<i>Ara militaris</i>
Yellow-billed Cuckoo	<i>Coccyzus americanus</i>
Broad-tailed Hummingbird	<i>Selasphorus platycercus</i>
Costa's Hummingbird	<i>Calypte costae</i>
White-eared Hummingbird	<i>Hylocharis leucotis</i>
Rufous Hummingbird	<i>Selasphorus rufus</i>
Broad-tailed Hummingbird	<i>Selasphorus platycercus</i>
Elegant Trogon	<i>Trogon elegans</i>
White-striped Woodcreeper	<i>Lepidocolaptes leucogaster</i>
Tufted Flycatcher	<i>Mitrephanes phaeocercus</i>
Olive-sided Flycatcher	<i>Contopus cooperi</i>
Greater Pewee	<i>Contopus pertinax</i>
Western Wood-Pewee	<i>Contopus sordidulus</i>
Willow Flycatcher	<i>Empidonax traillii</i>
Hammond's Flycatcher	<i>Empidonax hammondii</i>
Gray Flycatcher	<i>Empidonax wrightii</i>
Dusky Flycatcher	<i>Empidonax oberholseri</i>
Pacific-slope Flycatcher	<i>Empidonax difficilis</i>
Cordilleran Flycatcher	<i>Empidonax occidentalis</i>
Ash-throated Flycatcher	<i>Myiarchus cinerascens</i>
Western Kingbird	<i>Tyrannus verticalis</i>
Plumbeous Vireo	<i>Vireo plumbeus</i>
Cassin's Vireo	<i>Vireo cassinii</i>
Warbling Vireo	<i>Vireo gilvus</i>
Yellow-green Vireo	<i>Vireo flavoviridis</i>
Rock Wren	<i>Salpinctes obsoletus</i>
Rose-throated Becard	<i>Pachyramphus aglaiae</i>
Chihuahuan Raven	<i>Corvus cryptoleucus</i>
Brown-backed Solitaire	<i>Myadestes occidentalis</i>
Blue Mockingbird	<i>Melanotis caerulescens</i>
Black-throated Gray Warbler	<i>Setophaga nigrescens</i>
Townsend's Warbler	<i>Setophaga townsendi</i>
Fan-tailed Warbler	<i>Basileuterus lachrymosa</i>
Wilson's Warbler	<i>Cardellina pusilla</i>
Slate-throated Redstart	<i>Myioborus miniatus</i>

Table 4—Cont.

Spotted Towhee	<i>Pipilo maculatus</i>
Green-tailed Towhee	<i>Pipilo chlorurus</i>
Chipping Sparrow	<i>Spizella passerina</i>
Clay-colored Sparrow	<i>Spizella pallida</i>
Brewer's Sparrow	<i>Spizella breweri</i>
Lark Sparrow	<i>Chondestes grammacus</i>
Five-striped Sparrow	<i>Amphispiza quinquestrata</i>
Grasshopper Sparrow	<i>Ammodramus savannarum</i>
Hepatic Tanager	<i>Piranga flava</i>
Summer Tanager	<i>Piranga rubra</i>
Western Tanager	<i>Piranga ludoviciana</i>
Black-headed Grosbeak	<i>Phaeucticus melanocephalus</i>
Varied Bunting	<i>Passer inavensicolor</i>
Painted Bunting	<i>Passer inaciris</i>
Hooded Oriole	<i>Icterus cucullatus</i>
Lesser Goldfinch	<i>Spinus psaltria</i>

Conclusions

The fully protected NJR provides essential wintering and stopover habitat for migratory and important breeding habitat for over 200 species of birds. Foothills thornscrub, the Rio Aros, arid oak woodlands and an inland migration flyway are very likely essential components in the annual cycle of many Neotropical migratory species. Foothills thornscrub is apparently an undervalued biotic community for migratory birds. Data collected by NJP and their cooperators have established a baseline for monitoring long-term trends in the presence, abundance, and dispersal of birds in this region that may be due to the impacts of climate change or, we hope, to habitat protection efforts.

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Buying Land for Conservation Purposes in Sonora, Mexico

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***Abstract**— The Northern Jaguar Reserve is 50,000 acres and one of the largest privately owned wildlife preserves in Sonora. Buying land in remote parts of Sonora takes special knowledge as ownership rules may not be clear and boundaries may not be defined in the records. There are complex legal procedures to guarantee ownership in which letters of intent play a crucial role, and there are special complexities for ejido lands. In addition, only a presidential decree as a natural protected area can prevent mining in the long term. The lessons learned at the Northern Jaguar Reserve for conservation land purchases will be described.*

Introduction

Land purchase by organizations or individuals with the purpose of preserving its natural resources is only one of many other mechanisms for conservation with its advantages and disadvantages like any other. In the case presented here, it has been the most suitable mechanism because of the land tenure conditions in the Sierra of Sonora and because of the conflict between the main economic activity in the region, cattle-raising, and the main objective of the project developed by Naturalia, A.C. and the Northern Jaguar Project, protection of carnivores and their habitat. The expansion acquired by Naturalia and Northern Jaguar Project in the Sahuaripa municipality increases the number of acres to 51,346.10, becoming the largest private reserve in the State.

This paper presents a glance of the road followed to acquire that property, the obstacles found, and the remaining work to strengthen this conservation strategy, through appropriate legal means, which can guarantee our conservation objective in perpetuity. Land purchase is shown as a means to a goal—conserve jaguar habitat—not as a goal by itself. Learning from its limitations we must find alternative ways to preserve jaguar habitat, through community work or implementing public and governmental mechanisms that can achieve this goal.

Biodiversity Conservation In Mexico

Nature Preserves known as Natural Protected Areas (NPA) in Mexico have been the most common mechanism to protect representative portions of natural environments in the different biogeographic and ecological regions of the country's territory when these portions deserve to be preserved or restored because of their good condition

and their fragility or relevance on the maintenance of the regional ecological balance. For that purpose, the Mexican Legal System assigns to them a special protecting regime by the issuing of a presidential decree that limits land and natural resources use. Most of the NPAs are being established on private or social property, such as marine areas and island territories, with only a few terrestrial areas (e.g., the San Pedro's Sierra National Park in Baja California) demarcated in national property. More than 70% of the territory within NPAs is owned by private parties (Gutiérrez and others 2002). States and municipalities also have faculties to create NPAs in their own territories and by their own competence. Those areas, like the federal ones, can be established on private and social property.

The government has tacitly recognized that it is incapable of being in charge of protecting or restoring all the areas of biological importance that require it. This is evident in the increasing new rules directed at recognizing and encouraging civil society participation on conservation matters. Legal reforms to environmental Mexican Law (LGEEPA, its acronym in Spanish) in 1996 opened the door for registering units for wildlife management and conservation (UMA), which are private properties where the environmental authority allows wildlife management for restoration, protection, research, exhibition, recreation, and environmental education or sustainable development activities. With this mechanism, habitat preservation is also promoted, not just wildlife populations.

Since 1996, the 59th Article of LGEEPA provided for the possibility for owners and possessors who have biologically relevant lands to promote, by themselves, the establishment of a federal NPA for them. However, a decree process can take a long time and requires certain qualitative and quantitative land specifications to be able to be considered for some of the existing NPA categories. To improve and make this mechanism more inclusive, LGEEPA's regulations on NPA matters were issued in 2001. The Seventh Title of this regulation provided specific regulation for the referred article so that interested private owners could voluntarily request a certification of their properties as designated for protection, preservation, or restoration purposes of their land's natural resources. In contrast with federal, state, or municipal NPA, while those areas do not imply a decree process, they can be established temporarily for no less than 10 years. They do not require a minimum land extension but only well preserved conditions

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and it is the owner who defines the measure of the restriction for the use of his land and its resources. The Environmental Ministry (SEMARNAT) issues a certificate to the owner, which can be revoked if the conservation objectives are not met.

In some states, including Sonora, legislation has replicated these certification schemes with a few differences. Moreover, some states have recognized through their environmental laws some other mechanisms such as **conservation easements**—contractual commitments between private owners or between them and a government entity for natural resources protection in which the owners impose limits to their properties' use as recognition of the environmental services they provide; **rural reserves**— social properties destined for conservation purposes by the agrarian groups (from ejidos and communities) who are their owners; and **private gardens** with the objective of advancing native species conservation and regeneration.

Although governments have shown interest in integrating society to national conservation efforts, regulation is almost non-existent. Furthermore, paperwork requirements for getting a certification or a NPA decree are linked to the time and budget of the Public Administration. Another concern is that there is not any guarantee that a decreed NPA is effectively protecting the land and its resources because of many reasons including the lack of a designated budget, territory management issues, and diverse disagreements on public policies. Because of this, organized civil society has tried to apply or develop alternative mechanisms using existing civil regulations such as voluntary easements.

Any of those mechanisms require the owner's willing participation because the owners are the ones who will ultimately commit to manage land in an environmentally responsible way. However, it is common for owners' interests to change or to be incompatible with natural resources conservation. It is in these cases when non-governmental organizations with conservation purposes seek ownership of strategic properties to guarantee their long-term protection. In this manner, land purchasing constitutes another alternative mechanism to obtain the protection of ecosystems.

Northern Jaguar Reserve's Case

As part of the "borderlands jaguars" research efforts between Mexico and the United States, David E. Brown and Carlos A. López G. found that most of the available jaguar records of dead, captured, or photographed animals in Sonora between 1996 and 2000 were within a 50-mi radius where the Aros and Yaqui Rivers converge—they called this area Huasabas-Sahuaripa. The jaguar population in the area was still self-sustainable even though it had been over exploited (Brown and López 2001). Since then, the area has attracted the interest of researchers and has been visited or explored regularly. The area was also defined as the most northern region of jaguars in Mexico. Moreover, it has been cataloged as a Priority Terrestrial Region for Conservation by the National Commission for Biodiversity's Knowledge and Use (CONABIO) (Arriaga and others 2000). One of the land owners near the Aros River, close to where the Bavispe joins it to form the Yaqui River, offered one of his properties for sale in 2003, opening a unique land-purchase opportunity.

To obtain the first property for creating a "private reserve" where jaguars along with other associated species could be monitored and preserved, Naturalia, A.C. bought the property known as *Los Pavos de Arriba* and *Los Pavos de Abajo*, an area of 10,001.48 ac, on July 15, 2003. This is the how "Northern Jaguar Reserve" (RJV) was created. In the closing process, Naturalia was supported by the newly-formed Northern Jaguar Project. This purchase involved relatively little paperwork because the owner initiated the negotiation and there was

a proper title issued by Agrarian Ministry (SRA), which is not common in the region. Most of the lands are only "possessions," that is, irregular settlements where ranchers have lived for several generations. The Mexican Government recognizes these ranchers as "possessors" but not as owners because the properties that have not been titled in someone's name but rather are called original properties belong to the Nation. The process for obtaining a property title issued by the SRA begins through the possessor's request for buying the possession. The rancher must then demonstrate that he has been living on the land or that he has used that land for at least 3 consecutive years; that nobody argues against the boundaries of the requested land; and that the possession has to be paid to the Nation at a price depending on the land's quality or aptness for agricultural or forestry activities.

The Nation usually does not take actions to claim its property rights and, therefore, the possessors seldom need more legitimacy than that which already results from the acknowledgement of neighbors and the local authorities, the *Ayuntamientos*, which in fact recognize possession rights by registering them at the local cadastral office and by giving them access to productive subsidies. This way possessors do not feel compelled to regularize their possessed land while in practice they act as owners without needing to spend money they do not have in buying what they consider to be their own land.

Once Naturalia acquired the referred property, the livestock were removed and wildlife monitoring began though camera-traps placed on it and the neighboring properties once a signed collaboration agreement was in place. The results from the monitoring effort confirmed the presence of jaguar and other carnivores such as puma, ocelot and bobcat. Moreover, some other endemic species like eared trogon or endangered animals like military macaw occurred on the property. All of this increased the interest in this area and motivated the expansion project.

Expansion

After buying Los Pavos, Naturalia with its partner, NJP began negotiation with the owner of Zetazora, a group of four ranches adjacent to the south-side of Los Pavos. This negotiation was complicated, however, since the owner's expectations after the Los Pavos purchase had increased considerably. On the other hand, although all the properties had a proper title, not all of them came from SRA. They had diverse registration records and had belonged to different owners with some of them "regularized" by a declaratory judgment of ownership though a civil law procedure.

It is common among the possessors that have not obtained title by an agrarian procedure to go before a civil judge to ask for the "prescription" of their possessing rights through a voluntary jurisdiction— a non-contentious trial. Sonora's Civil Code and most of the civil law from other states allow a possessor to ask for a prescription that recognizes the possessor as the owner when they possess the land as if they were owners. That possession is recognized by society and, importantly, the owners of adjacent properties. The possession does not have to be registered under a person's name at Property and Commerce Public Register (RPP). In this case, the possession had been exerted for at least 3 or 10 years without anyone discussing.

Possessors usually do not have a problem in demonstrating their lawful possession as it is already recognized by municipal authority. The Municipality, moved by raising more taxes, gives them a cadastral number, but they do not have a public statement even though the land belongs to the Nation and, because of that, are not prescriptible. While there is not a Civil Code, a binding procedure that calls SRA to defeat Nation's interests when there is no public records at the RPP, a

judge can assess the requirements specified by that Code and grants land to the possessors applicant by prescription.

Having to deal with the owner through the different negotiation obstacles, Naturalia with NJP support acquired the group of four ranches, 34,904.87 acres in total size, on July 2, 2007, with an agrarian title and civil regularization. This purchase increased the area of the NJR three times. In 2008 and 2010, a search was made of the Sahuaripa's Municipal RPP and the Cadastre and Registration Institute of Sonora State (ICRESON) in Hermosillo, Sonora, to determine the status of each of the properties next to the NJR. This search was necessary because of the interest in acquiring some of these properties, and, therefore, knowledge of their legal status was necessary to determine that the lands were free from any lien or trial. Lands were removed from consideration when they lacked any kind of agrarian or civil regularization; were titled twice or had unfinished agrarian and civil procedures; were regularized by a civil procedure that had on-going agrarian procedures; had been decreed officially as public property; had prescription rights with non-viable limits or boundaries on reality; or lacked a will, were mortgaged without any kind of record, or had a lien.

This scenario led to negotiations with owners or possessors who had the "best titles," that is, at least had a civil title. This purchasing strategy has led to obtaining those ranches that were best located, favored reserve integrity, allowed for better management, and whose owners had wanted to sell. The last acquisitions were done on 2011. El Carricito, an area of 393.86 ac, was acquired as a possession in February so it had to be regularized through a civil procedure that was obtained by a favorable judgment on October of the same year. The property's use had been granted for life to her possessor to avoid destroying Sierra's culture and taking into account that livestock activity would be reduced considerably. The acquisition of Los Tezotaz' 5,873.62 ac followed in August. This ranch was partially titled because the will that entitled to the seller as possessor of the land referred to the "approximate surface" that coincided with the acreage surface for which a property tax was paid at the Municipality. It was necessary, however, to make a surface rectification. Finally, a small paddock of 171.66 ac was purchased. This paddock was inside Zetazora, one of the ranches already titled in Naturalia's favor and with an agrarian title. Even though the paddock was Naturalia's property, it had to be paid for to avoid a conflict by a possession that existed before Zetazora was purchased. Moreover, the paddock was a possession of the same person who sold Los Tezotaz; an opportunity of solving two negotiations in just one operation.

On-Going and Future Actions

Steps are being carried out to obtain an agrarian title from SRA for a ranch of about 5,239.17 acres called Los Pavos de Abajo or Cajón Babizoso. We are also waiting for the owner of the only legally titled ranch, Tinaja Ahogadora, to complete a divorce process so that he can dispose of the property as sole owner. In parallel, since about a year ago, we have been correcting the previous justification study through which Naturalia had proposed as NPA to the NJR under the category of a "flora and fauna protection area" to Environmental Ministry. The main purpose of this request is to protect the area from one of its principal threats—mining—since planned gold extraction is becoming more imminent.

The Mexican Constitution, in its 27th Article, states that mining veins, ledges, masses, or deposits are national property. If it is accepted that both mining and environmental protection are public utility causes, it is desirable to avoid getting into a debate of which one of them should prevail. Moreover, an NPA establishment will

allow a guaranteed federal zone or a riverbank strip of 10 m wide measured starting from the highest water river level destination of Aros' riverbed on the adjacent portion to the NJR for conservation purposes. This is because once the area had a formal decree, the National Commission of Natural Protected Areas would be able to request it for its own destination. At this time, Naturalia could only request it as a concession that must be paid periodically, being unaffordable on the long term.

Establishing NJR as an NPA perpetuates the area purposes even if Naturalia is absent. The actions of NPA administered by public administration are compensated because there is only one owner who is committed to conservation purposes. The owner would be in charge of its management having the advantage of possibly obtaining more financial resources, capturing greater economic incentives, and having access to some technical support and participation of the regional conservation strategy.

Conclusions

Even though there have been advances in regulations for encouraging participation of organization and civil society in environmental conservation matters, irregularities confronting land tenants are still an impediment for its consolidation. A clear title is required for developing or carrying out any environmental conservation activities. However, clear titles do not always exist, so buying possessions always carries a risk that not everybody is willing to afford or finance. Meanwhile, while inefficiency in the regulations of land possessions often forces an immediate review, it also allows working with local community since a different perspective, promoting that way an important social change.

While land purchases may not be the only means nor be isolated from other mechanisms to integrate governmental participation at almost any level, the purchases allow participation by the local population in an area's conservation. While the acquired properties may be a core area, their connection through biological corridors should be resolved with more than one organization and with people's support. Land purchases should be conceived as an additional protective layer that becomes a whole piece with all other environmental efforts directed to ecosystems' and priority regional species' conservation efforts.

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Amphibian Conservation

A Comparison of the Herpetofaunas of Ranchos Los Fresnos and El Aribabi in Northern Sonora, Mexico

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***Abstract**—To compare and contrast herpetofaunas at Ranchos Los Fresnos and El Aribabi in north-central Sonora, México, we conducted herpetological surveys during 2006-2011, contacted others working in these two areas, and queried 27 museums and collections for specimens collected at or near these ranches. Based on this work, nine and seven amphibian, and 27 and 24 reptile species are known to occur at Ranchos El Aribabi and Los Fresnos, respectively. Significant findings at Los Fresnos include presence of presumed Sonora tiger salamanders (*Ambystoma mavortium stebbinsi*), of which there are only three localities in México; Arizona treefrog (*Hyla wrightorum*) at several sites; and Mexican gartersnake (*Thamnophis eques*); and at El Aribabi, Neotropical whipsnake (*Coluber mentovarius*), a range extension of 144 km, Tarahumara salamander (*Ambystoma rosaceum*) near the northern edge of its range, and Mexican gartersnake. Both ranches support non-native American bullfrogs (*Lithobates catesbeianus*) and non-native fishes. Non-native crayfish (*Orconectes virilis*) are also present at Rancho Los Fresnos. In total, 46 species of amphibians and reptiles were found, 22 of which occur on both ranches. Rancho Los Fresnos supports high grassland species not found at El Aribabi, while a number of typically Sonoran Desert or foothills thornscrub species found at El Aribabi were not encountered at Los Fresnos.*

Introduction

Sonora is the second largest of the Mexican states and extremely diverse topographically and in regard to biological communities. Mesic mixed conifer forests in the mountains of the northeast contrast with the arid Gran Desierto de Altar of the northwest and tropical deciduous forests of the southeast. Sonora's herpetofauna reflects this diversity in that 37 and 141 species of amphibians and reptiles, respectively, have been documented in the state exclusive of its islands (Rorabaugh 2008). However, many areas of Sonora are poorly explored herpe-

tolegically and focused work often reveals significant range extensions, unexpected faunal associations, or other relationships. From 2006-2011, we conducted focused herpetological inventories at two ranches in northeastern Sonora: Rancho Los Fresnos and Rancho El Aribabi.

Study Sites

The 4,050-ha Rancho Los Fresnos, located about 35 km north-northwest of Cananea on the U.S.-Mexico border (figs. 1, 2), is owned by Naturalia, a conservation non-governmental organization. The ranch is characterized by rolling plains grasslands at 1,460-1,600 m, and is notable not only for its intact plains grassland community, but also its well-developed ciénegas and riparian corridors along Portrero del Alamos, Arroyo Los Fresnos, Arroyo Los Alisos, Agua Dulce, and other drainages (Varela-Romero *et al.* 1992). Oak savannahs in the northeastern portion of the ranch and occasional rocky outcrops increase the heterogeneity of amphibian and reptile habitats.

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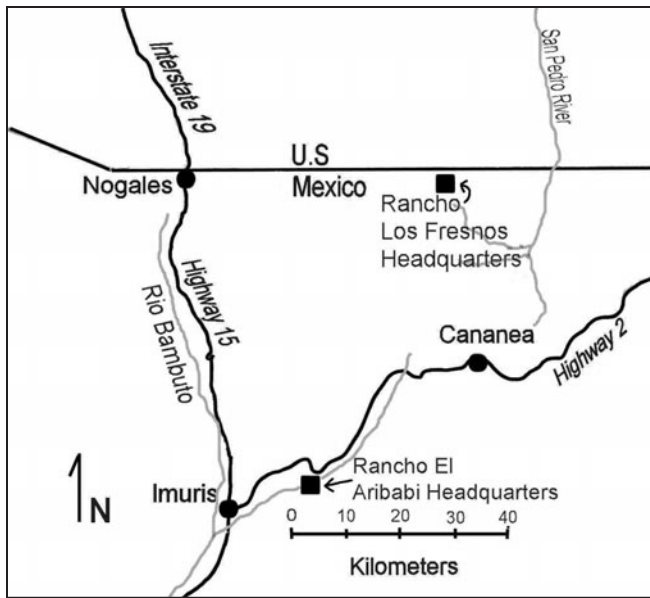


Figure 1 — Locations of Ranchos El Aribabi and Los Fresnos in the context of north-central Sonora, México.

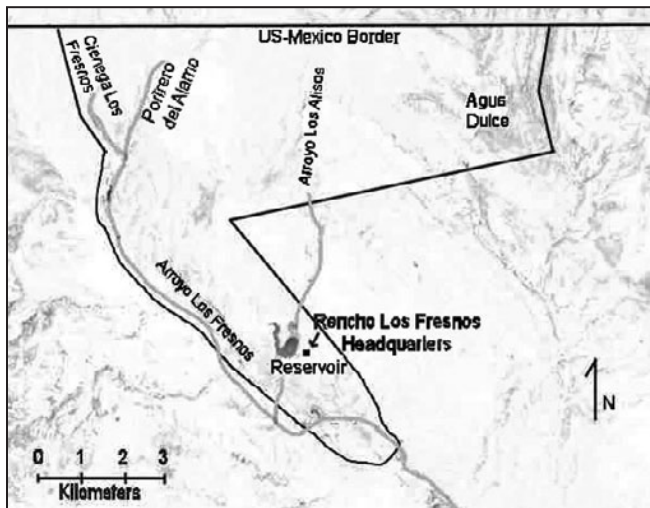


Figure 2 — Rancho Los Fresnos, approximately 35 km NNW of Cananea, Sonora, México.

Rancho El Aribabi, owned by the Robles family, extends over 13,000 ha and is located approximately 16-31 km northeast of Imuris (figs. 1, 3). El Aribabi includes biotic communities ranging from Sonoran desertscrub at the very lowest elevations (960 m) to mesquite grasslands, Madrean oak woodlands, and pine-oak woodlands at the highest elevations (about 2,000 m). The Río Cocospera, which includes an impressive riparian corridor and associated ciénega, runs through the western portion of the ranch. Much of our work was focused on the approximate 4,046 ha managed by Carlos Robles.

Naturalia recently acquired Rancho Los Fresnos and was interested in inventorying the ranch’s natural resources, including its herpetofauna. The U.S. Fish and Wildlife Service (USFWS) and Arizona Game

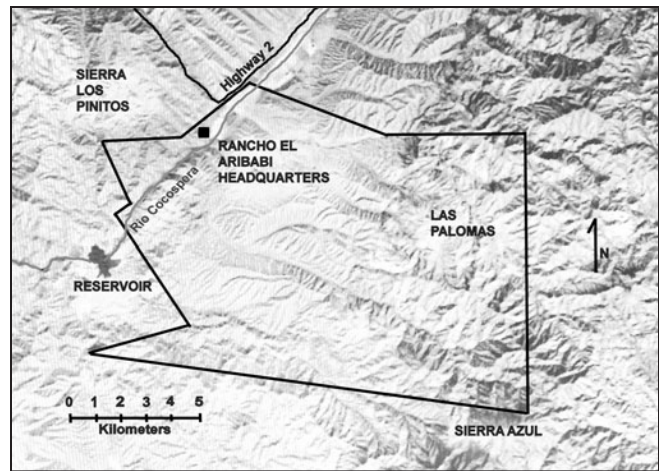


Figure 3 — Rancho El Aribabi, Approximately 16-31 km ENE of Imuris, Sonora, México.

and Fish Department (AGFD) were interested in the ranch as well, because of ongoing conservation and species recovery activities in the San Rafael Valley, Arizona, and the potential for complementary conservation at Los Fresnos, which is located in the southern portion of that valley. Carlos Robles was interested in pursuing federal reserve status for Rancho El Aribabi through México’s federal La Comisión Nacional de Áreas Naturales Protegidas (CONANP), and describing the ranch’s biological diversity was one of the first steps in that process. That federal reserve status was assigned to the ranch in May of 2011.

Materials and Methods

We used the following three methods to investigate the herpetofauna of Ranchos Los Fresnos and El Aribabi.

Herpetological Inventories

Rancho Los Fresnos was visited 22-25 May, 23-25 August, and 3-5 October 2006; and 17-19 September 2007. An initial reconnaissance was also made 20-21 December 2005 and additional herpetological records were obtained during amphibian workshops held 19-21 August 2008, 7-9 July 2009, and 20-23 September 2010; and a bat workshop held 6-10 June 2011. Rancho El Aribabi was visited 10-12 May, 20-22 September, and 6-8 October 2006; 20-22 April, 19-21 June, and 7-9 August 2007; 14-18 July 2008; and 18-20 November 2011. Inventories at both ranches included day and night visual encounter surveys, driving roads (especially just before and after dark), listening for calling amphibians, and hoop nets and Gee minnow traps placed in streams and ponds to capture tadpoles, turtles, and gartersnakes (*Thamnophis* sp.). We also employed a 10-m seine at cattle tanks at Los Fresnos to survey for amphibians. We made incidental observations of native and non-native fishes and introduced invertebrates, which can influence distribution or presence of native riparian or aquatic vertebrates (Rosen and Schwalbe 2002). Cover board arrays were used on a limited basis at Rancho El Aribabi, and at that ranch, concrete cattleguard boxes were found to act as opportunistic pit fall traps. One of us (C. Robles Elías) frequently visited El Aribabi and periodically photo-documented amphibians and reptiles in the course of other work. Due to good

accessibility, we were able to sample all biotic communities and most areas of the ranch at Los Fresnos; however, at Rancho El Aribabi, the majority of our work was done in the lowlands, and few trips were made into the higher montane woodlands. Due to poor access, we did not visit the pine-oak woodlands at Rancho El Aribabi, which occur in the extreme southeastern corner of the ranch in the Sierra Azul. Total person hours spent searching for amphibians and reptiles at Ranchos Los Fresnos and El Aribabi were approximately 381 and 343, respectively. Numbers of minnow trap and hoop net trap days (24-hour periods) were 17.0 and 49.0 at Rancho Los Fresnos and 5.3 and 28.5 at Rancho El Aribabi, respectively. Six 1-m² cover boards were also run for 2 days (12 trap days) along the Río Cocospera at Rancho El Aribabi. We attempted to photo voucher at least one of each species found at the ranches. Photo vouchers were deposited at the University of Arizona herpetological collection (UAZ).

Museum and Literature Searches

The museums listed in table 1 were queried for specimen data at and near Ranchos Los Fresnos and El Aribabi.

Interviews of Other Workers

We contacted others working in the area of the two ranches regarding their herpetological observations, including for Rancho Los Fresnos, biologists with BIDA (Biodiversidad y Desarrollo Armónico), students from the Universidad de Sonora, Sally Stefferud (retired U.S. Fish and Wildlife Service), and Peter Warren (The Nature Conservancy); and for Rancho El Aribabi, Dale Turner (The Nature Conservancy), Sergio Avila, Trevor Hare, and Tom Van Devender (Sky Island Alliance), and Tom Wood (Southeastern Arizona Bird Observatory).

Results

Our investigations, including herpetological inventories, review of museum collections, and interviews with others, documented nine and seven species of amphibians, and 27 and 24 species of reptiles at Ranchos El Aribabi and Los Fresnos, respectively (table 2). In total, 46 amphibian and reptile species were found at Ranchos Los Fresnos and El Aribabi, of which 22 occurred at both ranches (table 2), resulting in a Jaccard Similarity Index (Baroni-Urbani 1980) of $22/46 = 0.48$. All species were documented via our own observations, except for six found by others working in the area. No museum collections were definitively from the two ranches, although KUNHM specimens collected primarily by Joseph R. Alcorn in 1957 and 1958 at “9 mi NNE of Imuris” (table 3) may have come from Rancho El Aribabi. Alcorn’s locality plots in the Sierra Los Pinitos were about half way between the Río Bambuto and the Río Cocospera; the latter river is on Rancho El Aribabi. The collections include riparian species, such as Mexican gartersnake (*Thamnophis eques*), Sonoran mud turtle, and Lowland leopard frog (*Lithobates yavapaiensis*); however, habitat for these species is currently absent at 9 mi NNE of Imuris, and it seems likely that Alcorn collected either at the Río Bambuto or the Río Cocospera. Our efforts to locate Alcorn’s field notes or other clarification of the collection locality have been unproductive. As a result, for the purposes of tables 2 and 3 we have assumed these collections were made near but not within Rancho El Aribabi. Species not documented by us at El Aribabi or Los Fresnos, but which were found in museum collections or were reported by others from localities in contiguous habitats near the two ranches are noted in table 3.

Table 1—Herpetological museums queried for specimens collected at or near Ranchos El Aribabi and Los Fresnos.

Museum acronym	Full name
AMNH	American Museum of Natural History
ASU	Arizona State University Herpetology Collection
BMNH	Bishop Museum of Natural History
BYU	Brigham Young University
CAS	California Academy of Science
CUMV	Cornell University Museum of Vertebrates
KUNHM	University of Kansas Natural History Museum
INHS	Illinois Natural History Survey
LACM	Los Angeles County Museum
LSUMNH	Louisiana State University Museum of Natural History
MCZ	Harvard University Museum of Comparative Zoology
MSUM	Michigan State University Museum
MVZ	Museum of Vertebrate Zoology
PSM	Slater Museum of Natural History
ROM	Royal Ontario Museum
SDNHM	San Diego Natural History Museum
SU	Stanford University collections (housed at CAS)
TNHC	University of Texas at Austin
UAZ	University of Arizona Herpetology Collection
UCM	University of Colorado Museum at Boulder
UIMNH	University of Illinois Museum of Natural History
UMMZ	University of Michigan Museum of Zoology
UNAM	Universidad Nacional Autónoma de México
USNM	National Museum of Natural History
UTA	University of Texas at Arlington
UTEP	University of Texas at El Paso

Both ranches were found to support introduced predators. At Rancho Los Fresnos, we found American bullfrog (*Lithobates catesbeianus*) to be abundant and widespread, as well as introduced crayfish (*Orconectes virilis*), Green sunfish (*Lepomis cyanellus*), and Black bullhead (*Ameiurus melas*), which were locally abundant. The native Longfin dace (*Agosia chrysogaster*) was only abundant in Arroyo Los Fresnos. American bullfrog was found in the Río Cocospera at Rancho El Aribabi, but only appeared to be abundant in the pools at the ciénega, which is also the only area where we found tadpoles of that species. We found introduced Mosquitofish (*Gambusia affinis*) and Green sunfish in the Río Cocospera at Rancho El Aribabi during 2006-08, and Largemouth bass (*Micropterus salmoides*) was found in 2011. However, we also found native dace (*Agosia* sp.), Sonora chub (*Gila ditaenia*), and topminnow (*Poeciliopsis* sp.).

Discussion

Faunal Differentiation and Causal Factors

The herpetofauna of Rancho Los Fresnos is in part a grassland assemblage, as reflected in the presence of species such as Tiger

Table 2—Amphibian and reptile species documented by vegetation community type at Ranchos Los Fresnos and El Aribabi. “UAZ” indicates the species is photo-vouchered in the University of Arizona Herpetological Collection. If no voucher exists, occurrence is shown with an “X”. All species documented by the authors unless indicated in the footnotes.

Species	Rancho El Aribabi					Rancho Los Fresnos			
	Vegetation community type					Vegetation community type			
Amphibians	Sonoran Desert	Mesquite Grassland	Riparian/ Ciénega	Mesquite/ Oak Savanna	Oak Savanna	Plains Grassland	Plains Grassland/ Scattered Oaks	Riparian	Ciénega
<i>Ambystoma mavortium</i>							X ^a		X ^b
<i>Ambystoma rosaceum</i>		UAZ		UAZ ^c					
Anura									
<i>Anaxyrus punctatus</i>	X	UAZ	X	X		UAZ		X	X
<i>Anaxyrus woodhousei</i>		UAZ	X			UAZ		X	X
<i>Hyla arenicolor</i>		UAZ		X		UAZ		UAZ	
<i>Hyla wrightorum</i>								UAZ	UAZ
<i>Lithobates catesbeianus</i>			UAZ			X		UAZ	X
<i>Lithobates yavapaiensis</i>	X	X	UAZ						
<i>Incilius alvarius</i>		UAZ	X						
<i>Scaphiopus couchii</i>		X	UAZ						
<i>Spea multiplicata</i>		UAZ	X			UAZ		X	
Reptiles									
Testudines									
<i>Kinosternon sonoriense</i>			UAZ					X	UAZ
<i>Terrapene ornata</i>			UAZ			X			UAZ
Squamata - Lizards									
<i>Aspidoscelis burti</i>				UAZ					
<i>Aspidoscelis sonorae</i>		X	X	X		X		X	
<i>Coleonyx variegatus</i>		UAZ							
<i>Crotaphytus collaris</i>						UAZ			
<i>Elgaria kingii</i>			UAZ				X	UAZ	
<i>Heloderma suspectum</i>		X ⁴	UAZ						
<i>Holbrookia elegans</i>	X	X	UAZ			X		UAZ	
<i>Plestiodon callicephalus</i>			X						
<i>Phrynosoma hernandesi</i>							UAZ	X	
<i>Sceloporus clarkii</i>	X	UAZ	X	X		X		X	
<i>Sceloporus jarrovii</i>							UAZ		
<i>Sceloporus slevini</i>								UAZ	X
<i>Urosaurus ornatus</i>		X	UAZ	X		UAZ	X	X	
Squamata - Snakes									
<i>Coluber bilineatus</i>				X					
<i>Coluber flagellum</i>		X	X			X			
<i>Coluber mentovarius</i>				UAZ					
<i>Crotalus atrox</i>		UAZ	X			UAZ			

Table 2—Cont.

<i>Crotalus molossus</i>			UAZ		UAZ		X		
<i>Crotalus scutulatus</i>		X ^e				UAZ			
<i>Crotalus tigris</i>				UAZ					
<i>Diadophis punctatus</i>			UAZ						
<i>Heterodon kennerlyi</i>							X ^f		
<i>Hypsigena chlorophaea</i>		UAZ		UAZ			UAZ	UAZ	
<i>Micruroides euryxanthus</i>	UAZ								
<i>Pituophis catenifer</i>			UAZ				UAZ		UAZ
<i>Rhinocheilus lecontei</i>			UAZ				X ^f		
<i>Sonora semiannulata</i>									X ^b
<i>Salvadora grahamiae</i>							UAZ		
<i>Salvadora hexalepis</i>		X ^d					UAZ		
<i>Senticolis triaspis</i>		UAZ							
<i>Thamnophis cyrtopsis</i>			UAZ				UAZ		UAZ
<i>Thamnophis eques</i>			X ^g				UAZ		UAZ X ^b
<i>Trimorphodon lambda</i>		UAZ							

^aIn a cattle tank

^bReported by S. Stefferud

^cDocumented by R. Serraglio, S. Avila, and M. Quigley

^dReported by D. Turner

^eReported by T. Wood

^fPhotographed by students from the Universidad de Sonora, Hermosillo

^gReported by T. Hare

Table 3—Species present in museum collections or reported by others from localities close to Ranchos Los Fresnos or El Aribabi and in contiguous habitats.

Species	Locality and Museum
Rancho Los Fresnos	
<i>Lithobates chiricahuensis</i>	Bear Canyon, Huachuca Mountains, AZ, UAZ 24754
<i>Lithobates yavapaiensis</i>	2 mi NNE Sunnyside, AZ, UAZ 20294, 20273
<i>Diadophis punctatus</i>	Southern end of San Rafael Valley, AZ, JCR 0023
Rancho El Aribabi	
<i>Anaxyrus retiformis</i>	1 mi S Imuris, UAZ 31581-3
<i>Incilius mazatlanensis</i>	35 mi S Nogales, UIMNH 24455
<i>Smilisca fodiens</i>	1.5 mi N Imuris on Hwy 15, UAZ 31555
<i>Phrynosoma solare</i>	9 mi NNE Imuris, KUNHM 50729
<i>Sceloporus virgatus</i>	Sierra Azul, MABA son-trv-1418
<i>Crotalus willardi</i>	Sierra Azul (Campbell and Lamar 2004, MABA son-trv-1300)

salamander (*Ambystoma mavortium*), Mexican hog-nosed snake (*Heterodon kennerlyi*), and Slevin’s bunchgrass lizard (*Sceloporus slevini*); however, many of the upland species occur elsewhere in a variety of biotic communities, and many of the riparian forms (e.g. Canyon treefrog [*Hyla arenicolor*], Sonoran mud turtle, Black-necked gartersnake [*Thamnophis cyrtopsis*], and Mexican gartersnake) occur over a wide elevational range in a variety of community types. The presence of Yarrow’s spiny lizard (*Sceloporus jarrovi*), a montane species, is due to the rocky outcrops and oak savanna in the north-eastern portion of Rancho Los Fresnos, which is part of the bajada of the Huachuca Mountains in Arizona.

Species documented at Rancho El Aribabi reflect a greater range of community types, particularly emphasized by species more characteristic of lower elevations than are found at Rancho Los Fresnos (e.g. Couch’s spadefoot [*Scaphiopus couchii*] and Gila monster [*Heloderma suspectum*]). The influence of the Sonoran Desert and associated foothills thornscrub communities is in evidence at Rancho El Aribabi in the presence of Western banded gecko (*Coleonyx variegatus*), and species found nearby to the west in contiguous habitats, such as Sonoran green toad (*Anaxyrus retiformis*), Sinaloa toad (*Incilius mazatlanensis*), and Lowland burrowing treefrog (*Smilisca fodiens*; table 3). Rancho El Aribabi also exhibits a subtropical faunal influence with the presence of Tarahumara salamander (*Ambystoma rosaceum*), Neotropical whipsnake (*Coluber mentovarius*), and Green ratsnake (*Senticolis triaspis*). If we had been able to survey the higher elevations of the Sierra Azul more thoroughly, including

the pine-oak woodlands, we no doubt would have added species and broadened the ecological representation of species upslope at Rancho El Aribabi. Despite the differences ecologically, our data show that much overlap exists between the two ranches, as demonstrated by a Jaccard Similarity Index of 0.48.

Significant Observations and Range Extensions

On 25 August 1990, S. Stefferud, P. Warren, and others documented a larval Tiger salamander at Rancho Los Fresnos (S. Stefferud's field notes). Based on its location, the former was almost certainly a Sonora tiger salamander (*Ambystoma mavortium stebbinsi*), which is widely distributed just to the north of Rancho Los Fresnos in the San Rafael Valley in Arizona (Collins *et al.* 1988). The salamander was found in ciénega pools in Portrero del Alamo, and assuming it was a Sonora tiger salamander, this would be the only record of breeding in that subspecies outside of artificial impoundments (U.S. Fish and Wildlife Service 2002), and may represent a natural habitat used by these salamanders before European settlement. We also found breeding Tiger salamanders that we presumed to be Sonora tiger salamanders in a cattle impoundment in the northeastern portion of the ranch and at another cattle tank on the ranch just west of Rancho Los Fresnos. But because morphologically similar introduced Barred tiger salamanders (*A. t. mavortium*) have been found in some cattle tanks in the vicinity of Parker Canyon Lake, about 18 km north-northwest of the Los Fresnos headquarters, we cannot rule out that the salamanders at Los Fresnos are that subspecies. In 1990, S. Stefferud, P. Warren, and others also found an Arizona treefrog (*Hyla wrightorum*). We too found this species at several localities at Los Fresnos, and within Sonora those localities represent a range extension of approximately 235 km north-northwest from the closest record at El Chorro, 8 km northeast of Nacori Chico, Sonora (UAZ 45595), although the closest out-of-country record is ca. 13 km north in Arizona (Maldonado-Leal *et al.* 2009). The Los Fresnos localities are also unusual in that they are from aquatic sites in valley grasslands, whereas in Cochise County, Arizona, and sites elsewhere in Sonora, the Arizona treefrog is known as a montane or bajada species in woodland communities or from meadows within woodlands.

Although we did not find them, leopard frogs (*Lithobates chiricahuensis* and/or *L. yavapaiensis*) were likely present in the streams and ciénegas at Los Fresnos historically, as they occurred both in drainages upstream in the nearby Huachuca Mountains (table 3), as well as downstream in the San Pedro River (Clarkson and Rorabaugh 1989). No leopard frogs, American bullfrogs, or crayfish were noted by S. Stefferud in her field notes during her visit to the Los Fresnos in 1990, despite detailed observations on other amphibians, reptiles, fishes, and invertebrates. The only non-native species noted by S. Stefferud and others (Varela-Romero *et al.* 1992, S. Stefferud's field notes) were Mosquitofish (not found by us at Rancho Los Fresnos) and Green sunfish. It is likely that leopard frogs, American bullfrogs, and crayfish were scarce or absent in 1990. Sonoran mud turtles were present and often abundant in all of the permanent waters we sampled at Rancho Los Fresnos, and were also commonly found in the Río Cocospera at Rancho El Aribabi, thus effects of introduced predators on this species appeared to be minimal.

Mexican gartersnakes were found at both ranches. At Los Fresnos, four were observed along or near Arroyo Los Fresnos, where non-native predator densities appeared low and there was an abundance of native Longfin dace. As evidenced by flood debris in the trees and a severe flood we witnessed on the evening of 24 August 2006,

this arroyo is subject to periodic scouring, which tends to suppress non-native fish (Minckley and Meffe 1987), American bullfrog, and crayfish (Rorabaugh pers. obs.; also see Rosen and Schwalbe 2002) populations. S. Stefferud (field notes) observed a Mexican gartersnake in the Los Fresnos Ciénega in 1990. We observed several *Thamnophis* in that area, but we were unable to capture or identify them to species. Mexican gartersnakes may be persisting in the ciénega despite the presence of non-native predators. A single Mexican gartersnake was observed and photographed by Trevor Hare (Sky Island Alliance) along the Río Cocospera at Rancho El Aribabi. The only other gartersnakes observed at El Aribabi were two Black-necked gartersnakes (*T. cyrtopsis*), also found along the Río Cocospera. The apparent low density of gartersnakes was unexpected, because predator densities are relatively low outside of the ciénega and the habitat appears suitable. Eight Mexican gartersnakes collected by Alcorn at "9 miles NNE Imuris" (table 3) may have been collected near or perhaps at the Río Cocospera (see discussion above in the results section).

At Rancho El Aribabi, Sergio Avila and Carlos Robles Elías photo documented Neotropical whipsnakes on the northwestern slopes of the Sierra Azul (e.g. UAZ 56736-PSV), which extends the range 144 km north-northwest of the closest known locality (21 km northeast of Mazocahui on Highway 20, Sonora; Rorabaugh *et al.* 2009) and places this largely tropical species within 57 km of the Arizona border (Avila *et al.* 2008). Most records of this species in Sonora are from the southeastern portion of the state, south of Highway 16 (Rorabaugh *et al.* 2009). We also documented Tarahumara salamanders from two localities on the northwestern slope, as well as the northwestern bajada of the Sierra Azul (table 2); these localities are near the northern edge of the distribution of this species.

Species Likely to Be Found With Additional Effort

Figures 4 and 5 plot search effort (days) against cumulative number of species found for Ranchos Los Fresnos and El Aribabi, respectively. Both figures show that numbers of species found have plateaued, suggesting that adding species to the list will be time consuming and not very productive. Nonetheless, we believe several species not yet observed remain extant on the ranches. Species found nearby in similar habitats are listed in table 3. Of those, we believe all may occur on the ranches, with the exception of the Chiricahua leopard frog (*Lithobates chiricahuensis*) and Lowland leopard frog at Rancho Los Fresnos for the reasons discussed above. Other species that could be found include, for Rancho El Aribabi: Western narrow-mouthed toad (*Gastrophryne olivacea*), Barking frog (*Craugastor augusti*), Morafka's desert tortoise (*Gopherus morafkai*), Thornscrub hook-nosed snake (*Gyalopion quadrangulare*), Brown vinesnake (*Oxybelis aeneus*), and Chihuahuan mountain kingsnake (*Lampropeltis knoblochii*); for Rancho Los Fresnos: Desert grassland whiptail (*Aspidoscelis uniparens*), Ring-necked snake (*Diadophis punctatus*), and Chihuahuan hook-nosed snake (*Gyalopion canum*), and for both ranches: Black-headed snakes (*Tantilla* ssp.), and Common kingsnake (*Lampropeltis getula*).

Acknowledgments

We gratefully thank staff of the natural history museums listed in "Museum and Literature Searches" in the results section above for sharing museum records and discussing specimens. Juan Carlos Bravo and Gerardo Carreón of Naturalia provided access to and use of facilities at Rancho Los Fresnos, and we thank the Robles family

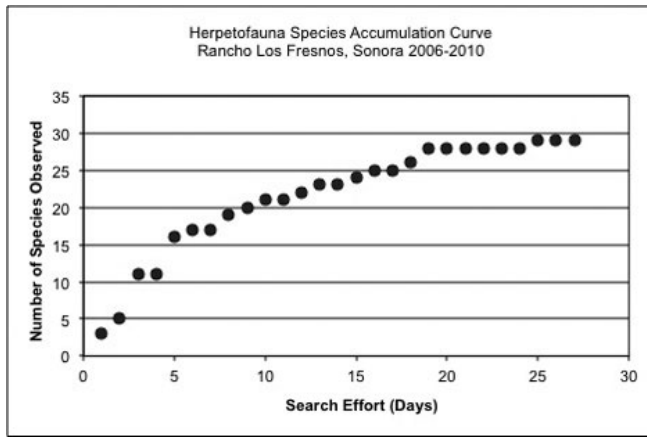


Figure 4—Species accumulation curve, Rancho Los Fresnos.

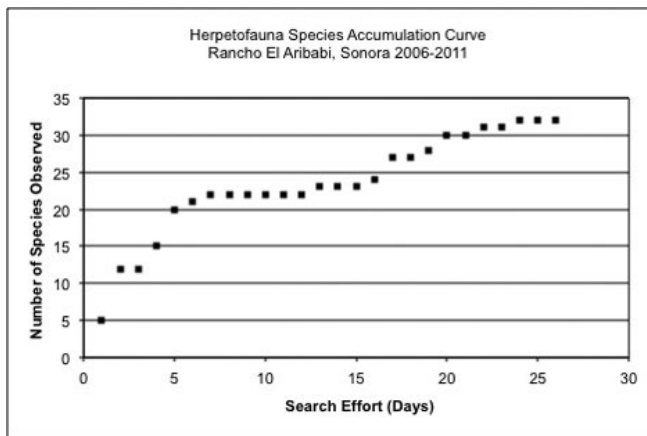


Figure 5—Species accumulation curve, Rancho El Aribabi.

for their hospitality at Rancho El Aribabi. Sergio Avila, students of Kevin Bonine's herpetology class at University of Arizona, students from the Universidad de Sonora, Antonio Esquer, Trevor Hare, Thomas R. Jones, Baruk Maldonado-Leal, Gricelda Meraz, Robert Mesta, Mike Quigley, Scott Richardson, Eduardo López Saavedra, Sally Stefferud, Robert Villa, Peter Warren, Tom Woods, and the

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Comparison of Preliminary Herpetofaunas of the Sierras la Madera (Oposura) and Bacadéhuachi with the Mainland Sierra Madre Occidental in Sonora, Mexico

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***Abstract**—Amphibians and reptiles were observed in the Sierra La Madera (59 species), an isolated Sky Island mountain range, and the Sierra Bacadéhuachi (30 species), the westernmost mountain range in the Sierra Madre Occidental (SMO) range in east-central Sonora. These preliminary herpetofaunas were compared with the herpetofauna of the Yécora area in eastern Sonora in the main SMO, where 92 species are known from the Río Yaqui to the Chihuahua border. The Yécora area, as we have defined it, extends from the Río Yaqui to the Chihuahua border along Mexico Federal Highway 16 and other areas accessible from it. Seven species in the Sierra la Madera are exclusive of the SMO fauna. Sky Island faunas are dominated by Madrean species, but also include species with tropical, desert, and northern temperate biotic affinities. Although the herpetofaunas of many Sky Island ranges in Sonora are not well documented, it is clear that the SMO fauna is much more diverse than any of them.*

Introduction

The fauna of the southwestern United States is famous for its diversity of amphibians and reptiles. The Madrean Archipelago is the area of isolated Sky Island (SI) mountain ranges between the northern Sierra Madre Occidental (SMO) in Sonora and Chihuahua and the southern edge of the Colorado Plateau (Mogollon Mountains and escarpment of the Mogollon Rim) in New Mexico and Arizona. High species richness in the region and each Sky Island is related to the convergence of five biotic provinces with diverse topography and habitats that converge in the area: tropical temperate SMO, temperate

Rocky Mountains, Great Plains-Chihuahuan Desert, Sonoran Desert, and the western Mexico low-lands tropics. The transition between the New World tropics and the northern temperate zone is at about 29°N in east-central Sonora.

In this paper, we summarize the amphibian and reptile faunas of the Sierra La Madera (SI) and the Sierra Bacadéhuachi (SMO) and compare them with the extensive herpetofauna of the Yécora area in east-central Sonora in the main Sierra Madre Occidental (Enderson and Bezy, unpubl. data).

Study Areas

The three study areas are all in east-central Sonora and are either in the Río Yaqui Basin or the adjacent Río Mayo Basin. Vegetation in all three areas ranges from lowland tropical skirts of foothills thornscrub (FTS) to oak woodland and pine-oak forest at higher elevations. The Sierra Bacadéhuachi is unique due to the occurrence of desert grassland between FTS and oak woodland in some areas. The Yécora area is substantially more tropical than the other two areas with tropical

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

deciduous forest (TDF) between FTS and oak woodland. We follow the classification used in Martin et al. (1998) for vegetation names.

Sierra la Madera

Sierra la Madera (= Oposura) is a Sky Island mountain range located (ca. 29°51'N to 30°10'N, 109°25'W to 109°42'W; fig. 1) between Óputo (= Villa Hidalgo) and Huásabas on the Río Bavispe to the east and between Cumpas and Moctezuma on the Río Moctezuma to the west (Yanes-Arvalo et al. 2011). Portions of the range are in the Municipios of Cumpas, Granados, Huásabas, Moctezuma, and Villa Hidalgo. Elevations range from 615 m at Huásabas and 660 m at Moctezuma to over 2300 m on the highest peak, an elevational range of about 1685 meters; Sierra la Madera is one of the higher ranges in Sonora. Most of the area is privately owned; the higher elevations are in Fracción V of the Área Natural Protegida Ajos-Bavispe. Cottonwood-willow forest occurs along the Ríos Bavispe and Moctezuma.

Sierra Bacadéhuachi

Sierra Bacadéhuachi, the westernmost mountain range in the Sierra Madre Occidental, is located east of Bacadéhuachi, Municipio Bacadéhuachi, 34 km east of the Chihuahua border, and 165 km south of the Arizona border (fig. 1). The southern portion of the Bacadéhuachi is in the Ríos Nácori Chico and Ríto drainages, with the Río Bacadéhuachi to the west. Elevations range from 700 m at Bacadéhuachi to about 2400 m on the highest peak, an elevational range of 1700 meters.

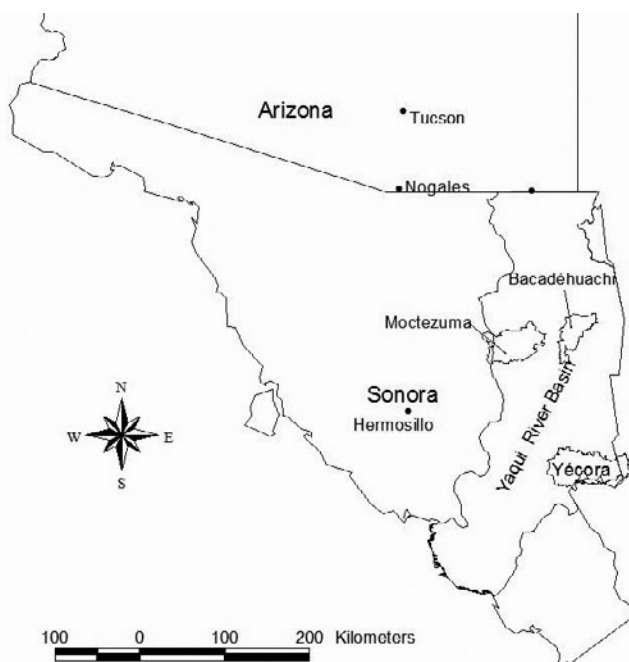


Figure 1—Sierra Bacadéhuachi, the westernmost mountain range in the Sierra Madre Occidental

Yécora Area

Yécora is a town in the SMO in east-central Sonora 42 km east of the Chihuahua border (fig. 1). Mexican Federal Highway 16 (MEX 16), one of the few highways that crosses the SMO, provides a west-to-east elevational transect from Río Yaqui (180 m) east to the Chihuahua border east of Yécora. The herpetofauna observations were in the Municipios de Yécora, Ónavas, and Soyopa. The vegetation gradient along MEX 16 is foothills thornscrub (180-550 m elevation), tropical deciduous forest (500-1,160 m), oak woodland (1,050-1,700 m), and pine-oak forest (1,220-2,140 m). Grassland occurs in high valleys (1,200-1,700 m) within oak woodland or pine-oak forest. Mixed-conifer forest (1,900-2,100 m) is present in Barranca El Salto on Mesa del Campanero. The elevational range is 1960 m, with 1660 m in the Municipio de Yécora.

Inventories

Sierra La Madera

Early collections in Sonora were made along two routes from the Arizona border that reach different sides of the Sierra la Madera; 1) Agua Prieta to Fronteras and Esqueda, south through Nacoziari de García and Cumpas to Moctezuma, mostly along the Río Moctezuma, and 2) Agua Prieta to Esqueda, southeast to the Sierra El Tigre, south along the Río Bavispe through Angostura and Óputo to Huásabas. Specimens of *Aspidoscelis exsanguis* from near Moctezuma were collected by S. B. Benson in March 1936 and J. E. Simpson in May 1938 (Museum of Comparative Zoology, MCZ, Harvard University). In the early 1950s, Paul S. Martin, University of Michigan, collected *Bufo alvarius* from west of Huásabas and *Crotalus atrox* and *Phrynosoma solare* from south of Óputo. Lowe and Woodin (1954) described *Masticophis flagellum* ssp. *cingulum* based on a specimen from Moctezuma. Michael D. Robinson collected in the Huásabas area for the University of Arizona Herpetological Collection (UAZ) in July 1969. As part of his study of the systematics of *Aspidoscelis*, John W. Wright collected in the Óputo-Huásabas area for UAZ, and the Los Angeles County Museum of Natural History (LACM) in July 1963, April 1966, July 1969, July 1974, July 1975, June 1980, and August 1982. Tod W. Reeder, San Diego State University, collected in the area for the Museo de Zoología “Alfonso L. Herrera” Facultad de Ciencias (MZFC, Universidad Autónoma Nacional de México). Arthur H. Harris and T. Paul Maslin, collected for the University of Colorado in the area in July 1970. Charles J. Cole collected in the area for the American Museum of Natural History in June 1988.

The other observations and collections in this study were made by the authors. Hale visited Arroyo la Saucedá in search of *Rana tarahumaræ* on November 1981 and October 1982, the latter trip with Cecil R. Schwalbe (Hale and Jarchow 1988), and in May 1998 with Ferguson, Peter A. Holm, and Elizabeth B. Wirt (Hale et al. 1998). Enderson, Turner, Hale, and Bezy visited the Sierra la Madera in September 2003 and Enderson and Bezy returned in July 2009. Areas visited included the microwave towers east-northeast of Cumpas and Rancho Mesa Quemada west of Huásabas. Van Devender, Turner, Villa, and Hedgcock visited the Sierra la Madera on a Madrean Archipelago Biodiversity Assessment (MABA) Expedition in June and July-August 2010, when a group of 38 scientists, researchers, students, volunteers, and agency biologists visited Ranchos Las Bateas, la Cieneguita, San Francisco, and Mesa Quemada, and the antenna area. Additional herpetologists in the group were R. Wayne Van Devender, Stephen L. Minter, Matt Nordgren, and Scott J. Trageser.

Sierra Bacadéhuachi

John W. Wright and James L. Patton in July 1967, Michael D. Robinson in July 1969, and Hale and Schwalbe in October 1982 collected specimens in the Bacadéhuachi area for UAZ. Later Wright collected in the area for LACM (July 1974) and with Allen E. Greer for MCZ (July 1975). Van Devender visited the Bacadéhuachi area in July 2008 and on MABA Expedition trips in June, August, and September 2011, and March 2012. Turner, Villa, Hale, Ferguson, and Hedgcock (also March 2012) were on the main expedition of 45 participants in August 2011, along with Will Lattea, Nordgren, Martín Villa, and Eric Wallace. Robert Villa and David J. Bygott were on the September trip. Our recent field activities in the Sierra Bacadéhuachi were centered on Rincón de Guadalupe in Arroyo Campo los Padres (29°50'40"N 108°58'37"W, 1680 m elevation).

Yécora Area

Between 1953 and 2005, amphibians and reptiles were collected in the Yécora area for UAZ on 33 trips involving 26 people. Primary collectors were Charles H. Lowe, Hale, Peter A. Holm, Darryl R. Frost, Julia V. Salmon, Brent E. Martin, and Cecil R. Schwalbe. Van Devender and Ana L. Reina-Guerrero made observations on 36 trips to the area from 1995 to 2008. Enderson and Bezy spent 40 field days investigating the Yécora area herpetofauna from 2004 to 2008.

Methods

Amphibians and reptiles were encountered during field searches and driving roads at night. Most areas were visited at different times of the day and in different seasons, but most effort was in the summer rainy season in July-September. Additional museum records were found in online databases such as VertNet (<http://vertnet.org/index.php>) and scientific publications, especially Rorabaugh (2008) and Enderson et al. (2009, 2010). Most historical records and our new observations and images are available in the MABA database (Madrean.org). Photovouchers of selected taxa were deposited into UAZ. Due to permit restrictions, animals were photographed but not collected.

Nomenclature follows Enderson et al. (2010) with a few exceptions. We follow Pauly et al. (2009) in the use of the traditional genera *Bufo* and *Rana*, rather than *Anaxyrus*, *Incilius*, or *Lithobates*. We use *Sonora aemula* rather than *Procinura aemula*.

Results

A total of 59 species of amphibians (11) and reptiles (48) are known from Sierra la Madera (table 1). A total of 30 species of amphibians (9) and reptiles (21) are known from Sierra Bacadéhuachi. In contrast, 92 species of amphibians (21) and reptiles (71) are known from along MEX 16 from the Río Yaquí at Tónichi through the Municipio de Yécora to the Chihuahua border. None of the species observed in the study areas are non-native.

Discussion and Conclusions

Biogeography

Several species observed in the Sierra Bacadéhuachi were range extensions of central SMO animals, notably *Bufo occidentalis*,

Craugastor tarahumaraensis (Ferguson et al. in press), and *Geophis dugesi* (Lemos-Espinal and Smith 2007; Villa et al. in press). Our observation of *Trimorphodon lambda* in pine-oak forest at Rincón de Guadalupe was the first record in the SMO; *T. tau* is common in various habitats in the Yécora area. A suite of typical SMO species, including *Crotalus lepidus*, *C. willardi*, *Elgaria kingii*, *Plestiodon callicephalus*, *Lampropeltis pyromelana*, *Sceloporus jarrovii*, *S. virgatus*, and *Senticolis triaspis*, are widespread in oak woodland and pine-oak woodland in Sky Island ranges in Sonora (Rorabaugh 2008; Enderson et al. 2010) and Arizona (Brennan and Holycross 2006).

A specimen from the Sierra la Madera was a typical *L. p. ssp. pyromelana*, but two specimens seen in the Sierra Bacadéhuachi appeared to be *L. p. ssp. knoblochi* X *L. p. ssp. pyromelana* intergrades (images with observations in the MABA database). Intermediate specimens in this intermediate site challenge recognition of *L. knoblochi* as suggested by Lemos-Espinal et al. (2003). A recent molecular study of *L. pyromelana* by Burbrink et al. (2011) not only concluded that they were separate species, but restricted the range of *L. pyromelana* to north of the Mogollon Rim in Arizona. Basing species and geographic distributions on non-selective molecular characters does not reflect the existing evolutionary hypotheses (subspecies) in any meaningful way. Extending the range of *L. knoblochi* into central Arizona would mean that most individuals in Sky Island populations half of its geographic distribution would not have the pattern characters typical of this subspecies.

Disjunct populations of a number of SMO amphibians and reptiles are known in Sky Island mountain ranges in Sonora (table 2). Hale collected *Salvadora bairdi* in Arroyo el Nogalito on the west side of the Sierra la Madera (UAZ 53743) in November 1981. This is a remarkable range extension of ca. 320 km north-northwest of Milpillas in the SMO on the Sonora-Chihuahua border (AMNH 102194). *Salvadora grahamiae* would have been expected instead.

A few species in Sierra la Madera are not known from the SMO (table 2). *Aspidoscelis opatae*, which is endemic to the Río Bavispe Valley (Enderson et al. 2010), occurs just south of Óputo. *Craugastor augusti* and *Oxybelis aeneus* are expected to occur in the Sierra la Madera. *Bufo woodhousii* and *Thamnophis marcianus* have been collected along the Río Bavispe just north of Óputo, and may be found farther south. *Aspidoscelis exsanguis* A. *tigris*, *Cophosaurus texanus*, *Crotalus atrox*, and *Heloderma suspectum* are desertscrub/desert grassland species reaching their western/southern limits in foothills thornscrub in central Sonora. *Plestiodon obsoletus* is a grassland species that is widespread in the Great Plains from Wyoming south to Texas and west to southeastern Arizona. Cliff (1953) reported it in Sonora from west of Huásabas. We observed one in the same area at Mesa Quemada in FTS in the southern Sierra la Madera. Quijada-M. et al. (2007) reported it from 34 km east of Hermosillo in foothills thornscrub/Sonoran desertscrub. In July 1975, Allan E. Greer collected one from near el Coyote (MVZ 137664), only 19 km north of Bacadéhuachi and just west of the Sierra Bacadéhuachi, almost in the SMO.

A few notably tropical animals reach their northern limits in the Sierra la Madera. *Leptophis diplotropis* is a colorful snake found in tropical western Mexico from Oaxaca north (Lemos-Espinal and Smith 2009). Most Sonoran records of this showy, aggressive snake are in TDF in the Álamos area, but McCoy (1964) reported it from along the Río Moctezuma south of Cumpas. This is a substantial record of a tropical species evidently using a river corridor to disperse northward. The nearest locality to Cumpas is Santa Rosa in the Municipio de Yécora, ca. 170 km to the south-southeast.

Until recently, *Sonora aemula* was known in Sonora only as a TDF species with most records from around Álamos, and a single locality

Table 1-Amphibians and reptiles in the Sierras la Madera (SM) and Bacadéhuachi (SB), and the Yécora area (YEC), Sonora, Mexico.

Taxon	SM	SB	YEC	Taxon	SM	SB	YEC
CAUDATA				TESTUDINATA			
Ambystomatidae				Emydidae			
<i>Ambystoma rosaceum</i>	x	x	x	<i>Terrapene nelsoni</i>		x	x
Plethodontidae				<i>Trachemys yaquia</i>	x		x
<i>Pseudoeurycea bellii</i>			x	Kinosternidae			
ANURA				<i>Kinosternon arizonense</i>			x
Brachycephalidae				<i>Kinosternon integrum</i>			x
<i>Craugastor augusti</i>	?		x	<i>Kinosternon sonoriense</i>	x	x	x
<i>Craugastor tarahumaraensis</i>		x	x	Testudinidae			
Bufo				<i>Gopherus morafkai</i>	x	x	x
<i>Bufo alvarius</i>	x	x	x	SAURIA			
<i>Bufo mazatlanensis</i>	x	x	x	Anguidae			
<i>Bufo mexicanus</i>			x	<i>Elgaria kingii</i>	x	x	x
<i>Bufo occidentalis</i>		x	x	Crotaphytidae			
<i>Bufo punctatus</i>	x	x	x	<i>Crotaphytus collaris</i>	x		
<i>Bufo woodhousii</i>	?			<i>Crotaphytis nebrius</i>	x		x
Hylidae				Eublepharidae			
<i>Hyla arenicolor</i>	x	x	x	<i>Coleonyx fasciatus</i>	?		x
<i>Hyla wrightorum</i>			x	Helodermatidae			
<i>Pachymedusa dacnicolor</i>			x	<i>Heloderma horridum</i>			x
<i>Smilisca baudinii</i>			x	<i>Heloderma suspectum</i>	x		
<i>Smilisca fodiens</i>	x	x	x	Iguanidae			
Leptodactylidae				<i>Ctenosaura macrolopha</i>	x		x
<i>Leptodactylus melanonotus</i>			x	Phrynosomatidae			
<i>Syrhophus interorbitalis</i>			x	<i>Callisaurus draconoides</i>	x		x
Microhylidae				<i>Cophosaurus texanus</i>	x		
<i>Gastrophryne olivacea</i>	x		x	<i>Holbrookia elegans</i>	x	x	x
Pelobatidae				<i>Phrynosoma ditmarsii</i>			x
<i>Scaphiopus couchii</i>	x		x	<i>Phrynosoma hernandesi</i>	x		x
Ranidae				<i>Phrynosoma orbiculare</i>			x
<i>Rana magnaocularis</i>	x		x	<i>Phrynosoma solare</i>	x		x
<i>Rana tarahumarae</i>	x		x	<i>Sceloporus albiventris</i>			?
<i>Rana yavapaiensis</i>	x	x	x	<i>Sceloporus clarkii</i>	x	x	x
				<i>Sceloporus jarrovi</i>	x	x	x
				<i>Sceloporus lemosespinalis</i>		x	x
				<i>Sceloporus poinsetti</i>			x
Taxon	SM	SB	YEC	Taxon	SM	SB	YEC
Phrynosomatidae (cont'd)				Colubridae (cont'd)			
<i>Sceloporus slevini</i>			x	<i>Leptodeira splendida</i>			x
<i>Sceloporus virgatus</i>	x	x	x	<i>Leptophis diplotropis</i>	x		x
<i>Urosaurus ornatus</i>	x	x	x	<i>Oxybelis aeneus</i>	?		x
Polychrotidae				<i>Pituophis catenifer</i>	x		x
<i>Anolis nebulosus</i>			x	<i>Pituophis deppei</i>			x
Scincidae				<i>Rhinocheilus lecontei</i>	x		x
<i>Plestiodon callicephalus</i>	x	x	x	<i>Salvadora bairdi</i>	x		x
<i>Plestiodon obsoletus</i>	x			<i>Salvadora deserticola</i>	x		x
<i>Plestiodon parviauriculatus</i>			x	<i>Senticolis triaspis</i>	x	x	x
Teiidae				<i>Sonora aemula</i>	x		x
<i>Aspidoscelis burti</i>	x		x	<i>Storeria storerioides</i>			x
<i>Aspidoscelis costata</i>		x	x	<i>Tantilla hobartsmithi</i>	x		

Table 1-Cont.

Taxon	SM	SB	YEC	Taxon	SM	SB	YEC
<i>Aspidoscelis exanguis</i>	x		?	<i>Tantilla wilcoxi</i>		x	x
<i>Aspidoscelis opatae</i>	x			<i>Tantilla yaquia</i>	x		x
<i>Aspidoscelis sonora</i>	x		x	<i>Thamnophis cyrtopsis</i>	x	x	x
<i>Aspidoscelis tigris</i>	x			<i>Thamnophis eques</i>	x		x
Boidae				<i>Thamnophis marcianus</i>	?		
<i>Boa constrictor</i>	x		x	<i>Thamnophis melanogaster</i>			x
Colubridae				<i>Thamnophis rufipunctatus</i>			x
<i>Coluber bilineatus</i>	x	x	x	<i>Trimorphodon lambda</i>	x	x	x
<i>Coluber flagellum</i>	x		x	<i>Trimorphodon tau</i>			x
<i>Coluber mentovarius</i>	?		x	<i>Tropidodipsas repleta</i>			x
<i>Diadophis punctatus</i>			x	Elapidae			
<i>Drymarchon melanurus</i>	?		x	<i>Micruroides euryxanthus</i>	x		x
<i>Geophis dugesii</i>		x	x	<i>Micrurus distans</i>			x
<i>Gyalopion canum</i>			x	Viperidae			
<i>Gyalopion quadrangulare</i>			x	<i>Crotalus atrox</i>	x		x
<i>Hypsiglena chlorophaea</i>	x		x	<i>Crotalus basiliscus</i>			x
<i>Imantodes gemmistratus</i>			x	<i>Crotalus lepidus</i>	x		x
<i>Lampropeltis getula</i>	x		x	<i>Crotalus molossus</i>	x	x	x
<i>Lampropeltis pyromelana</i>	x	x	x	<i>Crotalus tigris</i>	x		x
<i>Lampropeltis triangulum</i>			x	<i>Crotalus willardi</i>	x	x	x

Table 2-Herpetofauna summaries and comparisons.

Site	Effort	Elevation		Elevation	
		Low	High	Range	
Sierra la Madera (SM)	Moderate	615	2300	1685	
Sierra Bacadéhuachi (SB)	Moderate	700	2400	1700	
Yécora (YEC)	High	180	2140	1960	
Herpetofauna	Amphibians	Reptiles	Total		
SM	11	47	58		
SB	9	21	30		
YEC	21	71	92		
Shared	SM	SB	YEC		
SM	---	22	50		
SB	22	---	30		
YEC	50	30	---		
Amphibians					
Shared	SM	SB	YEC	Unique	
SM	---	7	11	SM	0
SB	7	---	9	SB	0
YEC	11	9	---	YEC	7
Reptiles					
Shared	SM	SB	YEC	Unique	
SM	---	15	39	SM	7
SB	15	---	21	SB	0
YEC	39	21	---	YEC	20

east-northeast of Ónavas (28°29'N; UAZ45675). Julio Lemos-Espinal found one at Tónichi on the Río Yaqui (28°36'N; CONABIO record). In 2012 Van Devender photographed another one east of San Pedro de la Cueva in the Sierra Agua Verde (29°16'N), extending the known distribution ca. 100 km north-northwest of the Ónavas locality and ca. 80 km north-northwest of Tónichi. Finally Roberto Hernández-Jimenez photographed *S. aemula* at Tonibabi Spring in the Sierra la Madera (29°51'N; Hugo Silva- Kurumiya, pers. comm., 2012), 150 km north of the Ónavas locality (new records and images in MABA database).

Biodiversity

Several factors influence biodiversity. Within a Sky Island, species richness is influenced by local factors such as area, elevational range, vegetation diversity, habitats, bedrock types, and land use history. Geographic location is important because, in general, species richness in many groups' biodiversity increases southward to more tropical habitats. Although the northernmost tropical deciduous forest is in the Sierra San Javier (28°35'N; 100 km south-southwest of Sierra La Madera, 120 km southwest of Sierra Bacadéhuachi), foothills thornscrub and its tropical elements occur in a wide transition between Sonoran desertscrub and oak woodlands in the Sky Island ranges and the mainland Sierra Madre Occidental. Also the nearness to the SMO is important because biodiversity in general is higher in the SMO than any Sky Island (see Reina-G. and Van Devender, 2005 for floristic comparison).

The documentation of biodiversity is strongly influenced by access (roads), nearness of research centers, and the inventory effort (number of trips, field time, etc.) and the number and skills of observers. Herpetofaunas are difficult to study for a variety of reasons. Many species only emerge from underground retreats to feed and breed during a short part of the warm season and especially during the summer rainy season. Nocturnal, secretive species are rarely encountered.

The herpetofauna of the Sky Island Sierra la Madera with 59 taxa is moderately well known. Its affinities are strongly Madrean with 88.1% of the fauna shared with the SMO. Except for the Río Bavispe Valley endemic *Aspidoscelis opatae*, the species not known from the SMO are desertscrub/desert grassland species that are Sky Island faunas that are widespread in the Sonoran Desert to the west and/or desert grassland to the north. Old records of several additional taxa from the Cumpas-Moctezuma area, including *Aspidoscelis uniparens*, *Phrynosoma cornutum*, *P. modestum*, *Sceloporus cowlesi*, and *Terapene ornata*, are desert grassland taxa not known from the SMO. These would be significant southern range extensions, but are not included in the present study until validated.

The Sierra Bacadéhuachi is in the SMO, but the known herpetofauna is small despite four visits by many observers. Moreover, the numbers of individuals, especially of typically common, easily-observed species (*Hyla arenicolor*, *Sceloporus jarrovii*, *Thamnophis cyrtopsis*, etc.) seen in our 2011-2012 fieldwork were low, suggesting the possibility that some recent catastrophe might have impacted their populations— perhaps the severe freeze of February 2-3, 2011. All of the Bacadéhuachi taxa occur in the Yécora area.

The Yécora herpetofauna is much richer than the Sierra la Madera fauna (table 2), and likely any Sky Island in Sonora. One species, the snail-eating snake *Tropidodipsas repleta*, is endemic to the Yécora area (Smith et al. 2005). Additional species known from the SMO may be added to the Yécora area. *Plestiodon brevirostris* (Rorabaugh, 2008) and *Salvadora bairdi* (AMNH 102194) are known in the SMO from near Milpillan on the Chihuahua-Sonora border, 120 km south of the Yécora area. Several species, including *Coluber taeniatus*, *Crotalus*

scutulatus, *Spea multiplicata*, *Thamnophis elegans*, and *T. sirtalis* occur in the Yécora area in Chihuahua to the east (Van Devender and Lowe 1977). *Sceloporus albiventris* is known from the Álamos and as far north as Zetasora on the Northern Jaguar Reserve north of Sahuaripa in TDF Rorabaugh et al. 2011), but not yet in the Yécora area. Another two amphibians and 12 reptiles (10 snakes) occur in TDF near Álamos, but have not yet been found near Yécora. We estimate the potential SMO herpetofauna in eastern Sonora at 113 species of amphibians (24) and reptiles (89). Colubrid snakes are especially diverse with 45 species, which contrasts with 187 species for Sonora as a whole, including 35 amphibian and 152 reptile species (Enderson et al. 2009).

With the exception of the Northern Jaguar Reserve north of Sahuaripa in FTS (Rorabaugh et al. 2011), there are no published herpetofaunas for eastern and northeastern Sonora. The two local herpetofaunas presented here and comparisons with the mainland SMO herpetofauna in the Yécora area help understand the regional biodiversity, but additional studies are needed in individual Sky Island ranges and other areas in the SMO. The fauna of the Tres Ríos area, the wettest highlands on the Sonora-Chihuahua border in the northernmost SMO, would be especially interesting.

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Rivers and Streams

Distribution of Riparian Vegetation in Relation to Streamflow in Pima County, Arizona

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Abstract—We compared the distribution of riparian forest and woodlands relative to water resource availability for a 2.3 million-acre region for the Sonoran Desert Conservation Plan (SDCP). Most of Pima County's riparian vegetation occurs along stream reaches that classify as ephemeral. Ninety percent or more of the mesquite woodlands, riparian scrub, and riparian strand classifications of the Brown, Lowe and Pase system are associated with ephemeral stream reaches in Pima County. Over half of the Sonoran cottonwood-willow vegetation is associated with stream reaches that classified as ephemeral. Conservation planning has often focused on protecting perennial stream habitat. Our results support the importance of identifying and protecting ephemeral and intermittent streams, particularly those having shallow groundwater tables, in the Southwestern United States.

Introduction

This paper examines the significance and conservation status of riparian vegetation along ephemeral streams in Pima County, with special emphasis on deciduous riparian forests.

Despite the importance of riparian areas in the arid and semi-arid regions of the Western United States, the availability of water to riparian vegetation cannot be spatially evaluated over broad regions, in part because of inconsistent and incomplete information. U.S. Geological Survey (USGS) topographic maps differentiate perennial from non-perennial streams. Neither topographic maps nor National Wetland Inventory maps differentiate intermittent flow reaches from ephemeral stream reaches, a crucial distinction for many aquatic and riparian species of the Western United States. While discrete discharges of groundwater to the surface are sometimes mapped as springs on USGS maps, shallow groundwater systems that never discharge to the surface escape notice. Complicating the matter, effluent discharges today support riparian areas along streams that would otherwise be dry except during storm events (Fonseca and Regan 2001). The 2.3 million-acre area within Pima County that was studied for the Sonoran Desert Conservation Plan (SDCP) is one region where stream inventory allows for a comparison of the distribution of riparian vegetation relative to water resources, across a diverse terrain.

Resource Inventory and Analysis

The water resource inventory for the Conservation Plan was initially conducted by Pima Association of Governments (PAG 2000) for all of Pima County outside the Tohono O'odham Nation. Surface flows were classified according to the United States Geological Survey (USGS) (Langbein and Iseri 1960) definitions to differentiate perennial, intermittent, and ephemeral reaches of streams. Where long-term stream flow extent monitoring (also known as "wet-dry" mapping) was available, the extent of flow during the driest conditions was used to define the perennial reach.

Surface Flow Definitions

Perennial: one that flows continuously.

Intermittent: one that flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous areas.

Ephemeral: one that flows only in direct response to precipitation, and whose stream is at all times above the water table.

The topology of the ephemeral stream centerlines was based primarily on Pima County staff's delineation of stream centerlines from orthophotographs at a scale of 1:12,000. In remote areas of western Pima County the 1:24,000 USGS digital line graphs were used.

Shallow groundwater systems were identified based on evidence of a water table within 50 feet of the land surface. This definition was based on evidence that groundwater at this depth could sustain mesquite bosques (ADWR 1994). Many of the larger zones were mapped using a combination of aerial photographic and topographic interpretation, and review and mapping of groundwater level information from various state and local agencies. The inventory of shallow groundwater systems was, and still is, incomplete, consisting only of the larger and better documented sites (PAG 2000).

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The inventory identified 66 perennial stream reaches and 120 intermittent stream reaches on 57 different streams (PAG 2000). Pima County later augmented the inventory with additional spatial coordinates for streams, springs, and shallow groundwater systems. The data layers are maintained as part of Pima County's Geographic Information System and made available to the public at <http://gis.pima.gov/maps/sdcp/>.

To support conservation planning, Pima County used the Brown, Lowe, and Pase digital classification system (Brown et al. 1979) to classify the distribution and extent of vegetation along the region's watercourses. The vegetation study area consisted of the 2.3 million acres of land within Pima County and excluded Wilderness, Monument, National Park, Refuge or Military Reservation, and areas under tribal control.

Over 100 U.S. Geological Survey orthophotoquads at a scale of 1:24,000 were used to delineate polygons of increased vegetation size and density or geomorphological evidence of hydrological patterns (Harris 2001). Biologists then assigned a vegetation classification to each polygon based upon field experience and existing data.

Vegetation polygons were classified to the "biome" level, with the exception of the Sonoran Riparian Deciduous Forest and Woodlands biome (BLP code 224.5), which was further subdivided to distinguish mesquite from cottonwood-willow forest (Harris 2000). In this paper, "riparian" vegetation refers to 200-series BLP biomes or associations.

The distribution of riparian vegetation along the watercourses was analyzed by intersecting watercourse centerlines with riparian vegetation polygons using ArcGIS 10. The miles of stream length was summed for the three types of flow and for the five categories of riparian vegetation.

Watercourse centerlines came from three files. "Wash" centerlines were based on delineations by County staff circa 1990, regardless of water resource availability. 'Istreams' and 'pstreams' were independently delineated by PAG in 2000 to identify intermittent and perennial stream reaches, respectively. To deal with overlapping centerlines in our analysis, we buffered 'istreams' and 'pstreams' and used the buffer zones to erase any adjoining centerlines from the 'wash' file. In areas where the thalweg of the channel had moved substantially over time, or where the topologies diverged, the two centerlines were retained as independent flow paths. This occurred along a few miles of the effluent-dependent Santa Cruz River.

Results

Over 320,000 acres of streamside vegetation was defined in 13 naturally occurring biomes. The vast majority (86%) of vegetation along streams in Pima County is classified as upland vegetation (table 1). The remaining 14% consisted of four distinct riparian vegetation communities, with the Sonoran Riparian Deciduous Forest and Woodland biome being the most common, at over 25,000 acres.

About 88% of this biome was mesquite "bosque" or woodland association. The remainder, some 3100 acres, was cottonwood-willow association (defined herein as 224.53 or 224.523).

The distribution of riparian vegetation communities is biased towards eastern Pima County (fig. 1). Interior Southwest riparian deciduous forest (223.2) is found primarily above 3000 feet, whereas mesquite bosques (224.52) are most common below 3000 feet. The majority of Sonoran cottonwood-willow forest (224.53) and riparian scrub (234.7) is found between 3000 and 5000 feet.

Most of Pima County's riparian vegetation (200-series Brown, Lowe and Pase classification) occurs along stream reaches that classify as ephemeral (table 2; fig. 2). Ninety percent or more of the mesquite woodlands, riparian scrub, and riparian strand plant communities are associated with ephemeral stream reaches in Pima County.

The Sonoran cottonwood-willow association of the Sonoran deciduous riparian forest and woodland biome is the type of plant community that is most closely, in the literature, tied to perennial or intermittent flow (e.g. Lite and Stromberg 2005). In Pima County, this association is more closely affiliated with perennial and intermittent flow than the other four riparian associations (table 2; fig 2). Still, over half of the Sonoran cottonwood-willow vegetation in our study area is associated with ephemeral stream reaches. Three-fourths of the cottonwood-willow vegetation was along a non-perennial reach.

Of the approximately 45 miles of Sonoran cottonwood-willow association found along ephemeral reaches, shallow groundwater conditions are known to occur along over 8 miles (18 percent). About 76 of the 410 miles of ephemeral streams having Sonoran mesquite woodlands are mapped as intersecting a shallow groundwater polygon (19%).

Discussion and Conclusions

Over 870 miles of ephemeral stream in Pima County possess some type of riparian vegetation. The majority of each of the five riparian vegetation associations was found along ephemeral, not perennial streams. Our results point to the importance of evaluating and protecting ephemeral streams for the significant habitat values they may provide to a wide array of wildlife. The degree of protection offered to ephemeral streams under the Clean Water Act is under debate (Levick and others 2008). Our results bolster evidence presented by Levick and others regarding the ecological functions of ephemeral streams.

Shallow groundwater conditions, including perched aquifers along streams, could explain the persistence of some riparian vegetation found along ephemeral streams. Past groundwater pumping has contributed to a loss of year-round flowing streams and riparian forests in Pima County, mainly at lower elevations (Scalero and Fonseca 2000). Even after the water table no longer discharges to the surface,

Table 1—Acres of vegetation in Brown, Lowe and Pase biome classification.

Brown, Lowe and Pase vegetation (biome) in acres	Upland biomes (sum of all 100-series)	Interior Southwest riparian deciduous woodland (223.2)	Sonoran riparian deciduous forest and woodland (224.5)	Sonoran deciduous riparian scrub (234.7)	Sonoran interior strand (254.7)
	269,281	5,833	25,437	7,752	5,337

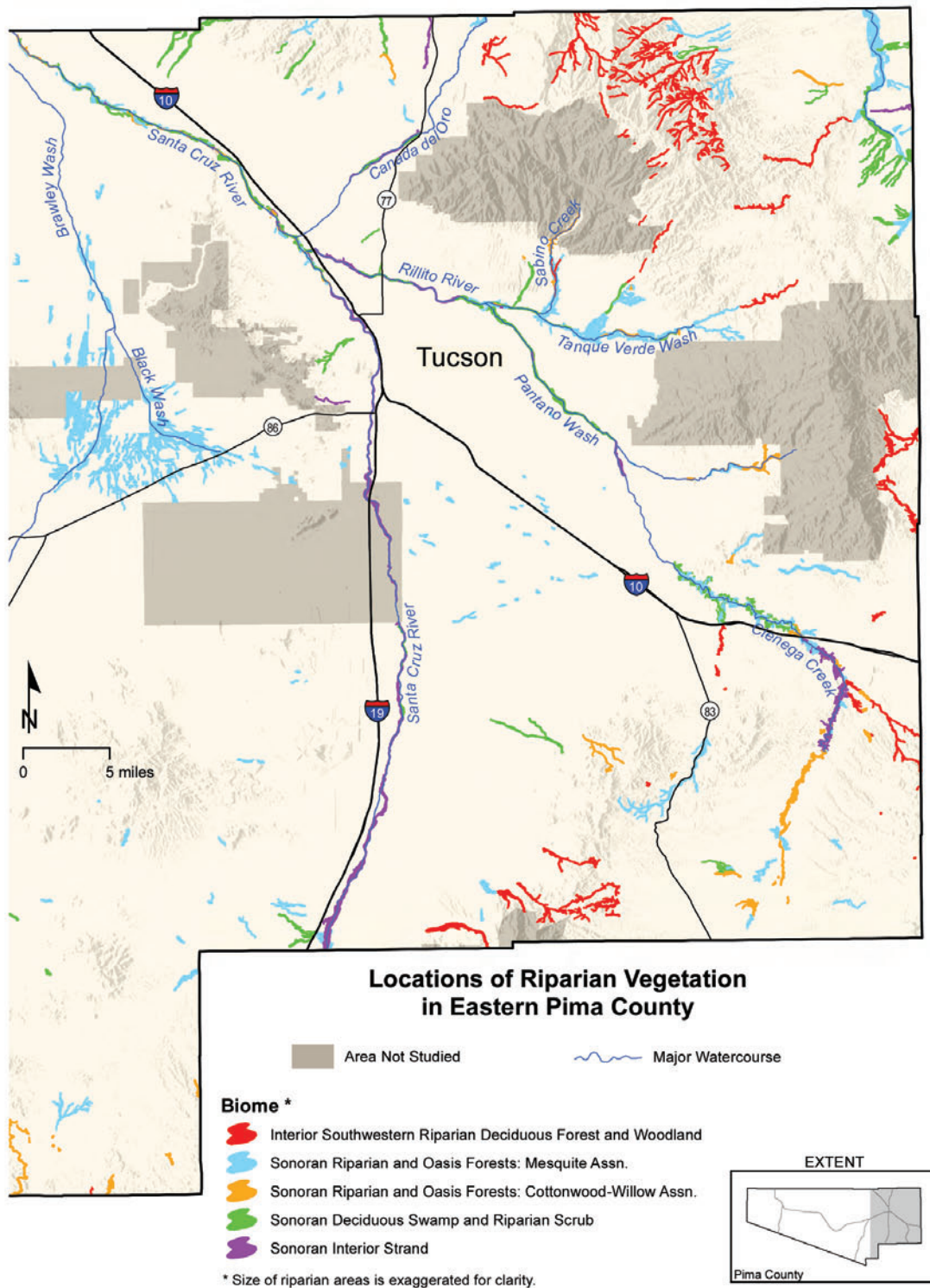


Figure 1—Location of riparian vegetation in eastern Pima County.

Table 2—Distribution of vegetation associations (Brown and others 1979) by stream flow type.

Flow type (reach miles) (%)	Interior Southwest riparian deciduous (223.2)	Sonoran mesquite woodland (bosque) (224.52)	Sonoran cottonwood-willow (224.53)	Sonoran deciduous riparian scrub (234.7)	Sonoran interior strand (254.7)	Total flow length in miles
Ephemeral	129 (73%)	410 (92%)	45 (56%)	163 (90%)	129 (96%)	877
Intermittent	36 (20%)	30 (7%)	17 (21%)	16 (9%)	4 (3%)	104
Perennial	13 (7%)	5 (1%)	19 (23%)	1 (1%)	1 (1%)	39
Total miles intersecting vegetation biome or association	178	446	81	181	134	1020

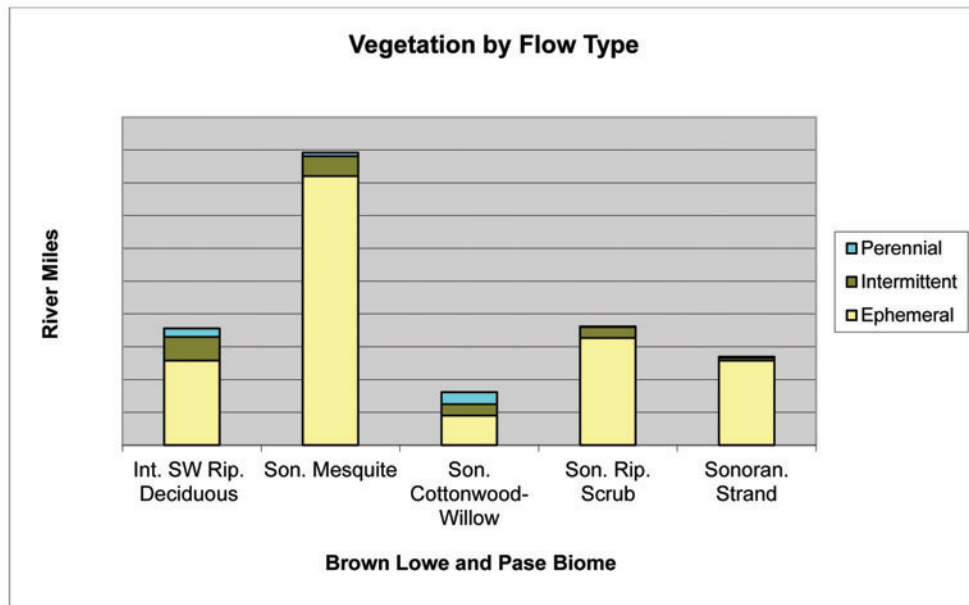


Figure 2—Vegetation by flow type.

shallow groundwater tables or moisture in the unsaturated zone below streambeds may remain accessible to streamside plants.

This study did not analyze vegetation condition across the spectrum of flow intermittency. Along the San Pedro River in adjoining Cochise County, dense, multi-aged cottonwood-willow forests appear to be restricted to perennial or intermittent rivers where depth to the water table is less than 4 meters (Lite and Stromberg 2005).

When analyzed for the Sonoran Desert Conservation Plan, only 63% of the Sonoran cottonwood-willow forest type was located within an existing reserve, a lower degree of protection that was available to many other, more common vegetation communities in Pima County (Fonseca and Regan 2001). About 75% of the higher elevation Interior Southwestern forests were protected, although much of that was within National Forests subject to mining and other competing interests.

Pima County and Pima County Regional Flood Control District have adopted a number of provisions to conserve riparian areas, including floodplain management regulations that pertain to riparian habitats found along the County’s predominantly ephemeral streams.

A 2004 general obligation bond for implementing the SDCP resulted in Pima County acquiring cottonwood-willow forests and mesquite bosques formerly subject to private land development, and managing state grazing leases that include additional riparian areas. Pima County holds and manages water rights associated with the land acquisitions. However, Arizona law provides little protection for groundwater-dependent ecosystems and no direct protection for the water needs of riparian vegetation (Losi 2012). These “sub-irrigated” ephemeral and intermittent streams are critical wildlife resources in arid and semi-arid areas like Pima County, Arizona.

Some 25 river miles of riparian vegetation along the Santa Cruz River is supported in part by effluent flows, supporting over 300 acres of riparian forest and woodland as well as riparian (Fonseca and Regan 2001). Continued discharge of effluent to the river depends largely on the actions of City of Tucson, which owns the majority of the effluent, and the Secretary of the Interior, who holds in trust 28,300 acre-feet of effluent for the benefit of the Tohono O’odham Nation.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Observations on the Seasonal Distribution of Native Fish in a 10-Kilometer Reach of San Bernardino Creek, Sonora, Mexico

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Abstract—San Bernardino Creek is a northern tributary of the Río Yaqui that originates in the United States and crosses the International Border just east of Douglas, Arizona/Agua Prieta, Sonora and immediately south of San Bernardino/Leslie Canyon National Wildlife Refuge. Six of eight Río Yaqui native fishes occur in this reach: four minnows, a sucker, and a poeciliid. Information is presented on the annual and seasonal distribution of these fishes during 2008–2011.

Introduction

San Bernardino Creek is a small northern tributary of the Río Yaqui drainage originating in the United States and crossing into Mexico about 16 km east of Agua Prieta and Sonora/Douglas, Arizona. It flows south to join Río Bavispe of Sonora and Río Papigochic of Chihuahua and becomes Río Yaqui, entering the Sea of Cortez near Ciudad Alvero Obregon (Hendrickson and others 1980).

Historically, San Bernardino Creek was a low-elevation, warm-water stream with alternating pools and riffles, undercut banks, and mud-gravel substrates. At one time, it also had considerable cienega habitat. This was before the San Bernardino Land Grant (~1820), after which, overgrazing and aquifer exploitation caused loss of aquatic habitats. These invasive management practices continued into the 1970s until the property was acquired by The Nature Conservancy who transferred the land to U.S. Fish & Wildlife Service (USFWS) creating San Bernardino National Wildlife Refuge (SBNWR) (Cobble 1995). However, by then, the impact of cattle and water mining had dramatically affected the watershed, leaving scars that can be seen today in the incised cienega deposits along San Bernardino Creek (Hendrickson and others 1980; Hendrickson and Minckley 1984; Cobble 1995). Impact on fish populations in the United States was extirpation of Yaqui sucker and near extirpation of Yaqui chub (Minckley and Marsh 2009). The status of fishes in Mexico during that time is unknown. Establishment of SBNWR included development of a management plan that focused on water conservation, aquatic habitat development, and native fishes restoration. These activities were augmented in Mexico with purchase of Rancho San Bernardino by Joe and Valer Austin in 1999, which includes San Bernardino Creek and the drainage to the south. Soon after its purchase, cattle were removed, ponds containing introduced fishes were drained, and a program of

gabion construction began in San Bernardino Creek and associated drainages of Hay Hollow and Silver Creek. These activities removed most introduced fishes and slowed erosion and raised groundwater levels, which resulted in the once barren channel of San Bernardino Creek developing dense stands of cattail and bulrush.

History of Fish Collections

The San Bernardino Creek drainage has eight species of native fishes including five minnows and one species each of sucker, catfish, and topminnow. The minnows are Mexican stoneroller, *Campostoma ornatum*; Mexican longfin dace, *Agosia* sp.; Mexican roundtail chub, *Gilaminacae*; beautiful shiner, *Cyprinella formosus*; Yaqui chub, *Gila purpurea*; Yaqui catfish, *Ictalurus pricei*; Yaqui sucker, *Catostomus bernardini*; and Yaqui topminnow, *Poeciliopsis sonoriensis* round out the fauna. Type locality for Yaqui catfish, Yaqui topminnow, Yaqui chub, Yaqui sucker and beautiful shiner is San Bernardino Creek at or near the International border (Girard 1857, 1859; E.A. Mearns cited in Snyder 1915).

Fish collections in Mexico from 1880 to 1980 are summarized in Hendrickson and others (1980) and include information on field collections by Simon in 1943, Frost and Hendrickson in 1944, and Miller and Winn in 1950. Fishes taken in these surveys included Yaqui chub, Yaqui catfish, beautiful shiner, Yaqui topminnow, and Yaqui sucker. Records also included carp, *Cyprinus carpio*; black bullhead, *Ameiurus melas*; and largemouth bass, *Micropterus salmoides*. Later, Varela and others (1990) reported rediscovery of Yaqui chub in the creek just south of the International Border and also later, downstream some 4 km from that border (Varela and Campoy-Favela 1996).

Surveys were initiated in San Bernardino Creek from the International Border to ~10 km downstream in May of 2008. This paper reports the distribution of native fish of San Bernardino Creek and some aspects of their biology between May 2008 and December 2011.

Materials and Methods

Four stations were established along San Bernardino Creek: Station one is four, 25-m reaches in Black Draw, which runs from the International Border south, 3 km; station two is downstream from

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the confluence of Black Draw and Silver Creek; station three is 3 km downstream from station two, and station four is 3 km downstream from station three. Stations two through four were 100 m in length. Stations were sampled with 12, fine-mesh, baited minnow traps and 6 1-m baited Promar hoop nets. All traps were set overnight and run in early morning. Fish collected were identified, counted, and released.

Results

Seasonal Distributions

Seasonal distributions are summarized in table 1. At Station one, the most common species was Yaqui topminnow, which was most abundant in fall and decreased in numbers into winter. Yaqui chub was the second most abundant fish and was distributed inversely to topminnow with highest percentages in winter, decreasing into fall. Longfin dace and Mexican stoneroller were present in small numbers throughout the year.

Yaqui topminnow was the most abundant fish overall at station two followed by longfin dace, which was most abundant in summer. Yaqui chub was present in small numbers in fall.

At station three, Yaqui topminnow was the most abundant species with peak numbers in fall. It was also abundant in winter after which decreased into spring and summer. Longfin dace was the second most abundant fish, with largest numbers present in summer and spring. It exhibited smallest numbers in winter and fall. Mexican stoneroller was not abundant but found here more than any other station with largest numbers occurring in summer and smallest numbers in winter. Yaqui topminnow was the most abundant fish at station four and was present in large numbers in fall, followed by summer. The smallest number of topminnow was present in winter and spring. Mexican stoneroller was represented in reduced numbers in all seasons with higher numbers being found in winter and spring (table 1).

Within Species Distribution

Yaqui topminnow was more abundant at stations two through four with largest numbers taken at station two and smallest at station one. This reflects habitat differences between station one, which has dense stands of cattail and bulrush, and other stations that are more open and more shallow. It might also reflect some level of predation on topminnow by Yaqui chub, which are abundant.

Yaqui chub was most abundant at Station one in winter when large numbers were taken. Numbers decreased into summer/fall. These numbers may reflect spawning, which occurs throughout the year, but appears most common in winter/fall (Minckley 2009, 2010). This would concentrate the fish and also increase number of young-of-year available for capture. During summer, the number of Yaqui chub drops and may reflect a reduction in movements to avoid higher water temperatures and anoxic conditions (Minckley 2010). Currently, Yaqui chub is reported to be restricted to the 3-km reach of station one (Minckley and Marsh 2009; Cobble 1995). This study has extended its range ~6 km and documented a large population in Los Ojitos Spring.

Mexican chub, *Gilaminacae*, was synonymized with roundtail chub, *G. robusta* (Miller 1976) but later resurrected based on molecular differences discovered by Dowling (1998) (Norris and others 2003). As discussed by Minckley (1973), "roundtail" were not thought to occur in San Bernardino Creek, but later he concludes that Mexican chub probably did occur historically in upper San Bernardino Creek based on its connection with Cajon Bonito (Minckley and Marsh,

Table 1—Percent of fish taken from four stations on San Bernardino Creek 2008-2011.

	Winter	Spring	Summer	Fall
Station 1, Black Draw				
Yaqui topminnow	35	54	62	79
Longfin dace	t	t	t	t
Yaqui chub	63	45	37	20
Mexican stoneroller	t	t	t	t
Station 2, Confluence				
Yaqui topminnow	88	92	67	89
Longfin dace	12	8	30	10
Yaqui chub	0	0	0	t
Mexican stoneroller	t	t	3	t
Station 3, Los Ojitos				
Yaqui topminnow	79	70	45	94
Longfin dace	16	28	41	5
Yaqui chub	t	t	t	t
Mexican stoneroller	5	t	13	t
Station 4, Las Anitas				
Yaqui topminnow	39	49	60	78
Longfin dace	58	49	39	19
Mexican stoneroller	4	2	t	t

2009). The two Mexican chubs taken in this study represent the first documented collections of this species from San Bernardino Creek.

Numbers of Mexican longfin dace and Mexican stoneroller are much reduced in station one. This is not surprising as both species are adapted to riffle/pool habitat, which is nonexistent in station one.

The last collection of beautiful shiner from the study area was in 1950 (Miller and Winn 1951). It was extirpated from San Bernardino Creek in the United States in 1970 (Minckley 1973; Minckley and Marsh 2005). In 1990, stock taken from Río Moctezuma, Chihuahua, and cultured at Dexter National Fish Hatchery & Technology Center, were repatriated into ponds on the SBNWR (Minckley and Marsh 2005). Today, populations on the refuge are large (B. Radke pers. comm.).

Yaqui sucker was extirpated from San Bernardino Creek in the United States in 1968 (DeMarais and Minckley 1993; McNatt 1974; Minckley 1973). There are no historical records of this fish from the study area although it is abundant in Cajon Bonito and is found in other areas of Mexico (Miller and others 2005; Minckley and Marsh 2009). Thirty-six Yaqui sucker from Cajon Bonito were introduced into San Bernardino Creek in August of 2008 on Station one. Adult individuals of this stocking have been taken but no reproduction has been documented (Minckley 2009; 2010).

Summary

San Bernardino Creek was surveyed for native fishes from the International Border downstream 10 kilometers during 2008–2011. Six native fish species were collected including Yaqui chub, Mexican chub, Mexican longfin dace, Mexican stoneroller, Sonoran topminnow, and Yaqui sucker. Yaqui chub was most abundant in station one and occurred downstream to station three. It was not taken further downstream but documented in Los Ojitos Spring. Two Mexican chub were taken from Station one, representing the first time this species has been documented from this drainage. Mexican stoneroller occurred throughout the study area. It was rare in station one but common in remaining stations. Mexican longfin dace was also rarely found in station one but was present in large numbers in other stations. Sonora

topminnow was throughout the study area and was more abundant from station two downstream. Depending on season and year, it could be represented by thousands of individuals. Yaqui sucker occurred in station one. Fish distributions were related to spawning, habitat types, and effects of summer water temperature and anoxic conditions.

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Biodiversity and Conservation of the Ciénega de Saracachi area, Sonora, Mexico

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Abstract—The Ciénega de Saracachi area, including Arroyo Santo Domingo and Cañón Quemado, is in the Municipio de Cucurpe in north-central Sonora (30°21'33"N 110°35'29"W), ca. 105 km south of the Arizona border. The vegetation is cottonwood-willow riparian forest in the Ciénega and rocky stream canyons with desert grassland on the slopes above. These upper tributaries of the Río San Miguel are natural corridors on the west side of the Sierras San Antonio and Azul. The flora contains 419 species in 99 families and the fauna 301 species of animals in 83 families. Invertebrate animals with only 87 taxa in 17 families are very poorly known. Vertebrate animals with 215 species in 67 families are dominated by birds (79.5% of the species). Two plants and 19 species of animals are Federally listed in Mexico in the NOM-059-SEMARNAT-2010. The *La Brisca* talussnail (*Sonorella aguafriensis*) is endemic to Arroyo Santo Domingo. In 2010, the Saracachi area was nominated to be a Sonoran Área Natural Protegida to preserve its natural values and to develop ecotourism land use options.v

Introduction

During spring break at the University of Arizona in 1976, Paul S. Martin lead a group of students from the Geosciences Department, to participate in the Easter festivities in Cucurpe and to visit Ranchos Agua Fría and la Brisca. Postdoctoral student Tom Van Devender was amazed by the lush cottonwood forest at the Ciénega de Saracachi with its permanent pools inhabited by Sonoran mudturtles (*Kinosternon sonoriense*) and Yaqui sliders (*Trachemys yaquia*).

The seeds from this trip are still growing. Van Devender developed a life long interest in the flora of the area, and began a study of amazing vertebrate fossils in a sediment pocket in Arroyo Santo Domingo. Ornithologists Stephen Russell (University of Arizona) and Gale Monson (U.S. Fish & Wildlife Service) made the first of six trips to the area to make bird observations for their remarkable, groundbreaking book, *The Birds of Sonora* (Russell and Monson 1998). Martin's legacy continues today as the Comisión de Ecología y Desarrollo Sustentable del Estado de Sonora (CEDES), the Sonoran state agency

of ecology and sustainable development, is in the process of having the area declared a state protected natural area. In April 2011, Van Devender led an international group of 40 biologists to the area on a Madrean Archipelago Biodiversity Assessment (MABA) Expedition to observe and catalog animals and plants in the area, 9 months after Martin's death at age 82. Here we summarize the biodiversity of this natural area in northern Sonora.

Methods and Results

Study Area

The Ciénega de Saracachi is in north-central Sonora (30°22'42"N 110°33'48"W), 12.3 km (by air) east-northeast of Cucurpe, Municipio de Cucurpe, ca. 105 km south of the Arizona border. The Ciénega is at 942 m elevation in the Río Saracachi (30°21'33"N 110°35'29"W), a northern tributary of the Río San Miguel, which joins the Río Sonora just north of Hermosillo. The study area includes Rancho Agua Fría and the Ciénega de Saracachi in the Río Saracachi, Rancho La Brisca in Arroyo Santo Domingo, and Cañón Quemado in Arroyo la Palmita. It covers an area of ca. 7.9 km² at 940-1000 m elevation centered on 30°22'42"N 110°33'48"W. These upper tributaries of the Río San Miguel are natural wildlife corridors on the west side of the Sierras San Antonio and Azul.

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Inventories

Plants—The earliest plant collections in the general area were by Thomas Sheridan and Gary P. Nabhan near Cucurpe in October 1975 and March 1976. The first collections in the Ciénega de Saracachi area were by Paul S. Martin, Mary K. O'Rourke, and Van Devender in April and August 1976. Martin returned to the area in June and September 1978, June 1981 (with Raymond M. Turner), May and September 1983 (with Jodie L. Duek), and April 1984. Van Devender has collected and observed plants in the Saracachi area on 17 trips between April 1976 and April 2012, accompanied by (in chronological order) Stephen F. Hale, Charles H. Miksicek, Niall F. McCarten, Kevin B. Moodie, Richard S. White, Kenneth L. Cole, Margaret C. Kearns, Vera Markgraf, Robert S. Thompson, Mary Erickson, Piet van de Mark, Philip D. Jenkins, George M. Ferguson, A. Lilia Reina-Guerrero, Martín Villa-Andrade, Gonzalo Luna-Salazar, Martín Reyes-Juárez, Mark Fishbein, Anurag Agrawal, Barbara G. Phillips, Laura Moser, John L. Anderson, Gertrudes Yanes-Arvayo, María de la Paz Montañez-Armenta, F. Isaias Ochoa-Gutiérrez, and Martín Padrés-Contreras. Ferguson and Hale also visited the area with Fishbein and Michelle McMahon in May 2000 and March 2001.

The flora of the Saracachi area contains 419 taxa in 301 genera and 99 families. This is based on at least 393 collections in the University of Arizona Herbarium (ARIZ), and 682 observations on an October 2010 and April-May 2011 Madrean Archipelago Biodiversity Assessment (MABA) scouting trip and Expedition. Most of these records are available in the Southwest Environment Information Network (SEINet)/MABA database (Madrean.org); Some of the older collections in ARIZ are not yet in the database.

Invertebrates—The few invertebrate observations from the study area were made on the MABA trips to the area. Van Devender photographed a small number of grasshoppers and dragonflies in 2010. John Palting made 100 observations of 77 species in April 2011. Robert A. Johnson observed six species of ants. Hugo Silva-Kurumiya from the Universidad de la Sierra collected a few terrestrial snails in the Ciénega de Saracachi in April 2011. Amy and Wayne Van Devender at Appalachian State University in Boone, North Carolina, identified them as *Gastrocopta cristata* and *Hawaiiia minuscula*.

Fishes—Alejandro Varela at the Universidad de Sonora inventoried the fish in the Ciénega de Saracachi in 1991, finding four species in three families. In April 2011, he found the same four species plus two non-native species: green sunfish/mojarra (*Lepomis cyanellus*) and largemouth bass/lobina (*Micropterus salmoides*).

Herps—Van Devender has made casual observations of amphibians and reptiles on 16 trips to the study area between April 1976 and May 2011, accompanied by (in chronological order) James A. Hudnall, Robert W. Van Devender, Villa-Andrade, Luna-Salazar, Reyes-Juárez, Ferguson, Hale, Eric Wallace, and Trevor Hare. The herpetofauna of the study area presently includes six species of amphibians in three families and twelve reptiles in seven families.

Birds—The primary bird surveys in the area were by Stephen M. Russell and Gale Monson who made 871 observations on six trips between April 1981 and April 1993. Villa-Andrade, Luna-Salazar, and Reyes-Juárez made casual observations as part of CEDES fieldwork. Carl Tomoff made 177 observations on the MABA Expedition in April-May 2011.

Mammals—Only casual observations of mammals have been made on trips to the study area.

Discussion

In 2010, the book *Diversidad Biológica de Sonora* edited by Molina-Freaner and Van Devender (2010) summarized the present knowledge of the abundance and distribution of plants and animals in Sonora. The Ciénega de Saracachi area is an important wetland natural area in north-central Sonora.

Flora Composition

The flora of the Saracachi area contains 419 taxa in 301 genera and 99 families.

The families with the most species are Asteraceae (61 taxa, 14.6%), Poaceae (48 taxa, 11.5%), Fabaceae (29 taxa, 6.9%), Solanaceae (14 taxa, 3.3%), Euphorbiaceae (13 taxa, 3.1%), Pteridaceae (12 taxa, 2.9%), Convolvulaceae (11 taxa, 2.6%), Lamiaceae, Malvaceae, and Scrophulariaceae (10 taxa, 2.4% each). The genera with the most species are *Bouteloua* (8 taxa), *Brickellia* and *Ipomoea* (7 taxa each), *Euphorbia* and *Muhlenbergia* (6 taxa each), and *Cheilanthes*, *Solanum*, and *Verbena* (4 taxa each).

Only Arizona walnut/nogal (*Juglans major*) and Santa Cruz striped agave/amole (*Agave parviflora*) have Amenazada (Threatened) Federal protection status protected in Mexico under NOM-059-SEMARNAT-2010 (Diario Oficial de la Federación, 2010), but the NOM list does not consider infraspecific taxa. *Agave parviflora* ssp. *parviflora* and the Santa Cruz beehive cactus/choyita cabeza (*Coryphantha recurvata*) in the study area are of special concern in Arizona. The subspecies *A. p.* ssp. *flexiflora* and *A. p.* ssp. *densiflora* are endemic to eastern Sonora (Starr and Van Devender, 2011).

Lumholtz false cloak fern (*Argyrochosma lumholtzii*), collected by Fishbein, McMahon, and Ferguson in Arroyo Santo Domingo, is a very rare endemic species only known from a few localities in Sonora. *Buddleja corrugata* ssp. *moranii* in the same area is a variety of a Baja California butterfly bush that is a rare Sonoran endemic.

Plants with northern affinities in the Saracachi flora include Arizona dewberry/zarzamora (*Rubus arizonensis*), goldenrod (*Solidago velutina* ssp. *sparsiflora*), stinging nettle/ortiga (*Urtica dioica* ssp. *gracilis*), rice cutgrass (*Leersia oryzoides*), and smallflower desert-chicory (*Pyrrhophappus pauciflorus*). The last two species are only known in Sonora from the Ciénega de Saracachi. Arroyo Santo Domingo has an unusual association of bigtooth maple (*Acer grandidentatum*, northern temperate), saguaro (*Carnegiea gigantea*, Sonoran Desert), and rock fig (*Ficus petiolaris*, tropical).

A number of tropical plants that are common in tropical deciduous forest and foothills thornscrub in southern Sonora are near their northern range limits in Arroyo Santo Domingo. These include a spurge/golondrina (*Euphorbia subreniformis*), rock fig, ortiguilla (*Gronovia scandens*), and gatuño (*Mimosa moniliformis*). Additional tropical species that also occur in Sonoran desertscrub in central Sonora include tree ocotillo/ocotillo macho (*Fouquieria macdougalii*), fragrant elephant tree/torote blanco (*Bursera fagaroides* var. *elongata*), papelío (*Jatropha cordata*), and organpipe cactus/pitahaya (*Stenocereus thurberi*). Chihuahua oak/*cusi peludo* (*Quercus chihuahuensis*) is a Sierra Madre Occidental and tropical species that was collected along the Río Saracachi just north of Cucurpe, but has not been found in the study area.

Twenty-four species were non-natives (5.7% of the flora, 8 grasses). Natalgrass/zacate rosado (*Melinis repens*), buffelgrass/zacate búfel (*Pennisetum ciliare*), and Johnsongrass/zacate juanón (*Sorghum halepense*) are invasive in some areas in Sonora, but not in the Saracachi

area. Watercress/*berro* (*Nasturtium officinale*) is potentially invasive in the stream in Arroyo Santo Domingo. Chinaberry tree/*piocha* (*Melia azedarach*), peach/*durazno* (*Prunus persica*), and pomegranate/*granada* (*Punica granatum*) are occasional survivors near old homestead sites in Arroyo Santo Domingo.

Vegetation

The vegetation in the Ciénega and in the rocky, incised stream canyon in Arroyo Santo Domingo is primarily cottonwood-willow riparian forest. Dominant species include Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), and Bonpland willow (*S. bonplandiana*). Netleaf hackberry/*cúmaro* (*Celtis reticulata*) and yewleaf willow/*tarais* (*S. taxifolia*) are locally common in the Ciénega. Huérigo (*P. monticola*) is near its northern distributional limit in Arroyo Santo Domingo. Arizona walnut is occasional in both areas. The floodplain of the Río Saracachi is dominated by velvet mesquite (*Prosopis velutina*). The slopes above the arroyos are in general desert grassland. One area in Arroyo Salsipuedes (an upper portion of Arroyo Santo Domingo) is foothills thornscrub.

Fauna

The insects are the largest and least studied group of animals. Additional inventories are needed in all areas in various seasons to better understand this fauna. The Mexican blue-winged grasshopper (*Machaerocera mexicana* (Behrstock and Sullivan 2011)), the arroyo grasshopper (*Heliasius benjamini*), and a tropical katydid (*Neobarrettia sinaloae*) found in Arroyo Santo Domingo in October 2010 were new species for Sonora.

Terrestrial snails are reasonably diverse, but secretive and little studied in Sonora. The endemic La Brisca talussnail (*Sonorella aguafriensis*) is only known from the original November 1984 collection by Russell Duncan in Arroyo Santo Domingo (Naranjo-García and Miller 1986). Snail inventories would be excellent additions to the biodiversity of the area.

The fish fauna with four species is well known in the study area. The native fishes in the entire Río Sonora basin include desert chub/*charalito sonorensis* (*Gila eremica*), Gila topminnow/*guatapote de Sonora* (*Poeciliopsis occidentalis*), topminnow/*charalito* (*Poeciliopsis* sp. nov.), longfin dace/*charalito aleta larga* (*Agosia chrysogaster*), Mexican stoneroller/*rodapiedras mexicano* (*Campostoma ornatum*), and Opata sucker/*matalote Ópata* (*Catostomus wigginsi*; Alejandro Varela-Romero, pers. comm. 2009). The Opata sucker is endemic to Sonora. The Opata sucker and Gila topminnow have the Mexican Federal status Amenazada in the NOM-059-SEMARNAT-2010 (Diario Oficial de la Federación 2010). Exotic green sunfish and largemouth bass should be monitored, and control programs are needed to protect native fishes.

Herpetofaunas are difficult to study for a variety of reasons. Many species only emerge from underground retreats to feed and breed during a short part of the warm season. Nocturnal, secretive species are rarely encountered. Six species of amphibians are known from the study area, but additional species are expected during the summer rainy season. At times, the lowland leopard frogs (*Rana yavapaiensis*) can be abundant. This frog is of special concern to state and federal agencies in the United States and Mexico because a chytrid fungus has caused population declines in many areas. The Arizona toad (*Bufo microscaphus*), which occurs primarily in Arizona, was found in the Ciénega in September 1990. Reptiles, with 13 species, are better known in the study area. Additional taxa, especially

snakes, will be encountered with more fieldwork. The northernmost population of the Yaqui slider (*Trachemys yaquia*) is in the Ciénega, and is considered threatened. Boa constrictor/*corua* (*Boa constrictor*), which was found in the Palm Canyon southeast of Magdalena (24 km northwest of the Ciénega) in September 1976, is expected to be in the study area. Six species of amphibians and reptiles (*Callisaurus draconoides*, *Coluber flagellum*, *Crotalus molossus*, *Elgaria kingii*, *Rana yavapaiensis*, and *Thamnophis cyrtopsis*) have the Mexican Federal status Amenazada or Protección Especial (Special Protection) in the NOM-059-SEMARNAT-2010 (Diario Oficial de la Federación 2010).

The birds, with 171 species in 40 families, are the best-studied group of animals in the study area (Russell and Monson 1998). Additional observations in spring and late summer would add information about Neotropical migratory species. Birds of special interest observed in the study area include Osprey (*Pandion haliaetus*) and Gray Hawk (*Asturina nitida*). The Yellow-billed Cuckoo (*Coccyzus americanus*) has been observed elsewhere in the Municipio de Cucurpe. Nine species are Federally protected in Mexico in the NOM-059-SEMARNAT-2010 (Table 1; Diario Oficial de la Federación 2010).

Mammals have been casually observed on various trips to the study area. The mammal fauna is presently at 19 species in 12 families. Camera traps would provide better documentation of what medium and large species occur in the area. Smaller species, especially bats and rodents, need to be inventoried to increase the biodiversity knowledge. Arizona gray squirrel (*Sciurus arizonensis*) in Arroyo Santo Domingo is a southern population of this regionally endemic species. Scat of American black bear/*oso negro* (*Ursus americanus*) was observed by Trevor Hare in Arroyo Santo Domingo in April 2011. Both species are Federally protected in Mexico in the NOM-059-SEMARNAT-2010 (Table 1; Diario Oficial de la Federación 2010). This arroyo is a potential corridor between the surrounding mountain ranges for dispersing animals, such as jaguar/tigre (*Panthera onca*) and ocelot (*Leopardus pardalis*).

Fossil Record

Van Devender et al. (1985) reported 51 taxa of vertebrates from the late Pleistocene Rancho La Brea Local Fauna in Arroyo Santo Domingo. The presence of *Bison* and *Mammuthus*—recent immigrants into North America from Siberia—indicated a late Pleistocene age for the deposit. The abundance of Sonoran mudturtles and leopard frogs (*Rana* “*pipiens*”, includes *R. yavapaiensis*) and the presence of a slider (*Pseudemys scripta*, now *Trachemys yaquia*), Red-winged Blackbird (*Agelaius phoeniceus*), and fishes (*Agosia*, *Catostomus*, and *Poeciliopsis*) indicated a paleoenvironment similar to the modern Ciénega de Saracachi before Arroyo Santo Domingo was down cut. The extinct La Brea Owl (*Strix brea*) was in the fauna. Additional large mammals in the fauna were a burro-sized horse (*Equus* cf. *tau*), a large horse (*Equus* sp.), a camel (*Camelops* sp.), four-horned antelope (*Tetrameryx* sp.), and mule deer (*Odocoileus hemionus*). Today white-tailed deer (*O. virginianus*) is common in the area. A number of species indicate warmer and/or more tropical environments than today, probably in the last interglacial period. These included Arizona mudturtle (*K. arizonense*), barking frog (*Craugastor augusti*), Kellogg’s toad (*Bufo* cf. *kelloggii*), Neotropical whipsnake (*Coluber* cf. *mentovarius*), and sabinal frog (*Leptodactylus melanonotus*).

Conclusions

The species richness in the riparian wetland habitats in the Ciénega de Saracachi, Arroyo Santo Domingo and Cañón Quemado is very

Table 1—Species protected in the NOM-059-SEMARNAT-2010. A = Amenazada (Threatened), P = Peligro (Endangered), Pr = protección especial (Special Protection).

Family	Species	Common name	Status
Plants			
Juglandaceae	<i>Juglans major</i>	Arizona walnut	A
Agavaceae	<i>Agave parviflora</i>	Santa Cruz striped agave	A
Fish			
Catostomidae	<i>Catostomus wigginsi</i>	Opata sucker	A
Poeciliidae	<i>Poeciliopsis occidentalis</i>	Gila topminnow	A
Amphibian			
Ranidae	<i>Rana yavapaiensis</i>	Lowland leopard frog	Pr
Reptiles			
Anguidae	<i>Elgaria kingii</i>	Arizona alligator lizard	Pr
Colubridae	<i>Coluber flagellum</i>	Coachwhip	A
Colubridae	<i>Thamnophis cyrtopsis</i>	Black-necked garter snake	A
Phrynosomatidae	<i>Callisaurus draconoides</i>	Zebra-tailed lizard	A
Crotalidae	<i>Crotalus molossus</i>	Black-tailed rattlesnake	Pr
Birds			
Accipitridae	<i>Accipiter cooperii</i>	Cooper's Hawk	Pr
Accipitridae	<i>Accipiter striatus</i>	Sharp-shinned Hawk	Pr
Accipitridae	<i>Buteogallus anthracinus</i>	Common Black-hawk	A
Anatidae	<i>Anas platyrhynchos diazi</i>	Mexican Mallard	A
Falconidae	<i>Falco columbarius</i>	Merlin	A
Strigidae	<i>Bubo virginianus</i>	Great Horned Owl	A
Strigidae	<i>Glaucidium gnoma</i>	Northern Pygmy-Owl	A
Strigidae	<i>Micrathene whitneyi</i>	Elf Owl	P
Vireonidae	<i>Vireo bellii</i>	Bell's Vireo	P
Mammals			
Sciuridae	<i>Sciurus arizonensis</i>	Arizona Gray Squirrel	A
Ursidae	<i>Ursus americanus</i>	American black bear	P

diverse with 419 plant taxa and 215 vertebrate taxa. The invertebrate fauna has 87 taxa, but is only a sparse beginning of the true diversity. The endemic La Brisca talussnail and several other species are the only known Sonoran from the area.

A total of 21 species (2 plants, 19 animals) are Federally protected in Mexico under NOM-059-SEMARNAT-2010 (Table 1; Diario Oficial de la Federación 2010). Thirteen species have the status Amenazada, three Peligro (= Endangered), and three Protección Especial. The three Peligro species are American black bear (*Ursus americanus*), Bell's Vireo (*Vireo bellii*), and Elf Owl (*Micrathene whitneyi*).

In 2010, CEDES submitted a proposal to the Governor of Sonora to declare The Ciénega Saracachi area a state protected natural area to conserve and restore structure and function of these important wetland habitats and to preserve the rich diversity of plants and animals.

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Biodiversity

Preliminary Assessment of Biogeographic Affinities of Selected Insect Taxa of the State of Sonora, Mexico

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Abstract—The biogeographic affinities of butterflies (Lepidoptera: Papilionoidea and Hesperidae), damsel and dragonflies (Odonata), and ants (Hymenoptera: Formicidae) reported from the State of Sonora, Mexico were analyzed using published species lists. The combined distribution of these taxa was proportionally greater (47.4%) for those species within the Mega-Mexico3 biogeographic category (Southwestern United States south to northern Central America). Formicidae was the most highly restricted taxon with greater proportions of Sonoran desert endemics. Butterflies had a greater proportion of tropical species (82.8%), whereas dragonflies and damselflies from Sonora were most widely distributed either north or south of Mega-Mexico. Differences in the biogeographic affinities of the three insect taxa are attributed to specificity of immature host plants and the distribution and persistence of species habitats.

Introduction

Sonora is a state with high biodiversity (Molina-Freaner and Van Devender 2010). The state is the second largest in Mexico and traditionally considered a transition zone between the Nearctic and Neotropical biogeographic realms. The state contains portions of three biogeographic provinces within its boundaries (Morrone and others 2002) including the major portion of the Sonoran province, the most northern extension of the Sierra Madre Occidental Province, and the extreme northwest portion of the Mexican Plateau. Marshall and Liebherr (2000) report that the region contains important areas of endemism and these are distinct from endemic species from mountains (Sky Islands) of southeastern Arizona.

Although the information concerning the insects of Sonora has been enriched in recent years (Bailowitz and Palting 2010), the number of insects reported from the state is still limited, given its area and biological diversity with overrepresentation of several orders. Of the records in the Madrean Archipelago Biodiversity Assessment database, and from records of the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO), there are reported a total of 10,341 insect specimen records. Of these records, 65% are Lepidoptera, 12% are Odonata and 9% are Hymenoptera. This is a typical collection bias (butterflies and dragonflies) for many relatively poorly collected areas. However, research efforts, some of which have been promoted through CONABIO and other agencies in Mexico, have led to the publication of many national, state, and regional flora and faunistic studies such as Llorente-Bousquets and others (1996), Rojas (2001), García-Mendoza and others (2004),

Garwood and Lehman (2005), Upson and others (2007) and Bailowitz and Palting (2010), which now allows for comparisons of species compositions of selected taxa between regions in Mexico.

In the present study, we analyzed previously compiled data from various sources of the species reported from the Mexican state of Sonora for three of the better known taxa: butterflies (Lepidoptera: Papilionoidea and Hesperidae), damsel and dragonflies (Odonata), and ants (Hymenoptera: Formicidae). Our general hypothesis was that the geographic affinities of the majority of species from these three taxonomic groups reported from Sonora fit into a distribution within the boundaries of “Mega-Mexico 3” (herein, Mega-Mexico) of Rzedowski (1998), a term equivalent to “Mexican Transition Zone” of Halffter (1987). We further delineated biogeographic categories for species with distributions within and/or beyond Mega-Mexico, and discuss species with unique distributions. A comparison of species compositions of selected butterfly groups between other Mexican states and Arizona is also presented.

Materials and Methods

Species lists of butterflies were recorded from Bailowitz and Palting (2010), as well as Scott (1986), DeVries (1987), Llorente-Bousquets and others (1996), Rivera Granados (1998), Garcia Jimenez and Guevara Guerra (2005), Garwood and Lehman (2005), Warren and others (2012) and Opler and others (2012). Species lists for Odonata included Westfall and May (1996), Ramirez and others (2000), Upson and others (2007), Bick and Mauffray (2011), and Paulson and Gonzalez-Soriano (2012). Lists of ant species were compiled from the list of the Ants of Sonora, Mexico, compiled by the ASU Social Insect Search Group (2012), and Rojas (2001),

The geographic distributions of species of butterflies, Odonata and ants were divided into four general biogeographic categories: (1) Mega-Mexico, (2) Tropical, (3) Temperate, and (4) American. The category Mega-Mexico corresponded to “Mega-Mexico 3” of Rzedowski, (1993), a distribution that includes the extreme southwestern United States, Mexico, and northern Central America (to northern Nicaragua). Tropical species were those that occur within Mega-Mexico, some

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of which extended as far north as the southwestern United States, but are recorded south beyond northern Central America into southern Central America and/or into South America. The species categorized as temperate species had distributions extending north of the southwestern United States (north of the limits of Mega-Mexico 3), with distributions extending south into Mexico and, rarely, into northern Central America. American species were those with ranges from the central to the northern United States, and/or Canada, into south Central America and/or South America and/or the Caribbean.

Within each of the four categories, further categories were grouped based on previously reported discontinuities reported by Halffter (1987): the Transverse Volcanic Belt, and the Isthmus of Tehuantepec. Thus, species from Mega-Mexico were further subdivided into (1) species found throughout Mexico, and also south of the Isthmus of Tehuantepec; (2) species with ranges in north and central Mexico but found only north of the Isthmus of Tehuantepec; (3) Northern species found north of the Trans volcanic axis; and (4) Sonoran endemics. Temperate subcategories were based the separation of eastern and western north America, an important pattern noted by Noonan (1988) and included (1) species from Sonora that extended to the western Rocky Mountain States north of Mega-Mexico, sometimes into Canada, but not into the central or eastern United States; (2) species reported from Sonora but did not extend into the Rocky Mountains and found in the southeast and/or central eastern United States; and (3) species from Sonora found in both the eastern and western United States, sometimes also into Canada. Subcategories of tropical species from Sonora were (1) species whose range extended south into southern Central America (south of Nicaragua); (2) those reported into southern Central America and the Caribbean; and (3) species extending into South America and the Caribbean.

Comparison of proportions between biogeographic categories among taxa were made using a χ^2 pairwise analysis and species composition between regions with a cluster analysis using Jaccard's index. The cluster analysis was conducted using representative regions (states) within Mexico (Veracruz, Tamaulipas, Chiapas, Querétaro, and Sonora) and the State of Arizona. The butterfly families Pieridae and Papilionidae were used as these taxa had the most complete and comparable data. Both analyses were performed with the PAST® statistical software program (Hammer and others 2001).

Results

The combined distribution of butterflies, dragonflies, damselflies and ants were proportionally greater for those species within the Mega-Mexico 3 biogeographic category (47.4%), followed by species with Tropical distributions (28.2%), Temperate (13.5%), and American (10.8%). Of the species within Mega-Mexico, the greatest proportion of species (27.3%) had distributions southward from Sonora, but not extending beyond the Isthmus of Tehuantepec with 13.9% found from Sonora into south Mexico or beyond into northern Central America. All other subcategories (species extending beyond MegaMexico to the north, south, or both) had 11% or less of the species totals. Species endemic to the Sonoran desert accounted for 6.3%, of which 76.9% were species of ants.

The proportions of species within these four general biogeographic categories were not similar between the three taxa compared (fig. 1) and all pairwise comparisons were significantly different ($\chi^2 > 40$, $df = 3$, $p < 0.01$). Formicidae was the most highly restricted taxon with 82 species (78.1%) found only within Mega-Mexico, and of these, 30 species 28.6% were classified as Sonoran desert endemics. Of the species from Mega-Mexico, 50 species (47.7%) were found from the Sonoran desert and into parts of central Mexico and only two species

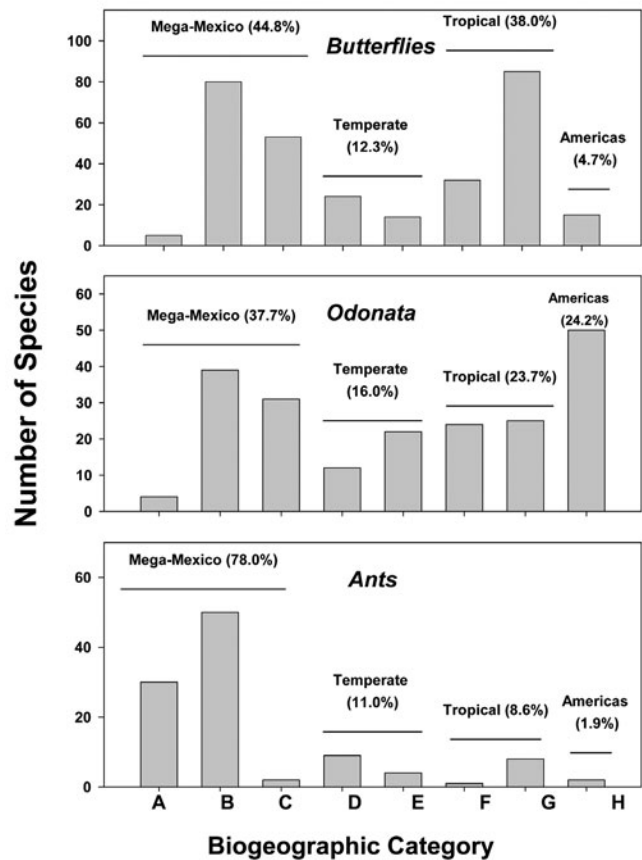


Figure 1—Biogeographic affinities of species of butterflies (Lepidoptera), dragonflies and damselflies (Odonata) and ants (Hymenoptera: Formicidae) reported from the State of Sonora, Mexico. A. Species endemic to the Sonoran Desert region (United States and Mexico); B. Species of reported within the southwestern United States and/or north and central Mexico but found only north of the isthmus of Tehuantepec; C. Species of reported within the limits of Mega-Mexico including regions north isthmus of Tehuantepec, and also from southern Mexico and/or northern Central America; D. Species restricted to Mega-Mexico to the south and also found in the western United States; E. Species restricted to Mega-Mexico to the south and also found in the eastern and western United States; F. Species restricted to Mega-Mexico to the north and also found in the southern Central America; G. Species restricted to Mega-Mexico to the north with ranges extending into South America, and/or the Caribbean; H. Species with ranges extending both north and south of the limits of Mega-Mexico.

(1.9%) extended beyond the Isthmus of Tehuantepec. Only 12 ant species (11.4%) found in Sonora had distributions extending northwards beyond the southwestern states (fig. 1), nine (8.6%) extended into Central America and beyond, and only two were found in both temperate and tropical latitudes.

Butterflies also had notable proportions of species from Mega-Mexico (fig. 1), but had a greater proportion than the other taxa of tropical, wide ranging species (82.8% either from Mega-Mexico or further south). These extended primarily from the northern limits of Mega-Mexico into southern Central America (32 species; 10.4%) or beyond into South America and/or the Antilles (85 species; 27.6%). Sonoran butterflies that had both temperate and tropical latitudes accounted for less than 5 percent of the species.

Species of dragonflies and damselflies from Sonora were the most widely distributed of the three taxa. Almost half (47.9%) of the species found in Sonora were also reported from southern Central America, the Antilles, and/or the South America, or had even greater distribution range from the eastern or western United States south beyond the southern limits of Mega-Mexico. The Odonata also had the greatest number of species from Sonora that were also found in the central and/or eastern United States (84; 35.7%).

Comparisons of species compositions of Pieridae and Papilionidae butterflies reported from Sonora with other regions indicated an expected differentiation between southern and northern Mexican regions with important differences between the adjacent States of Sonora and Arizona (fig. 2). For Papilionidae, there was greater similarity between Sonora and the northeastern State of Tamaulipas, over 1000 km to the east, than to adjacent Arizona. The species composition of Pieridae indicated that Sonora was the most different from all regions with less than 40% shared species with Arizona and Tamaulipas, with the southern states forming a cluster similar to that found with Papilionidae. The central State of Querétaro did not align with the

northern regions, but with Veracruz and Chiapas; this despite its connection with Tamaulipas through the Sierra Madre Oriental and having regions of Chihuahuan desert “relicts” (Morafka 1978), which share arid adapted plant species with northeastern Sonora (Morrone and others 2002).

Discussion

Biogeographic distributions are the product of ecological constraints and past geological events (Endler 1982; Casazza and others 2008; Kalkman and others 2008). However, separating these factors and specific methods, such as phylogenetic reconstructions, is difficult (Endler 1982), and not within the scope of the present study. However, a comparative approach may give preliminary insights into explaining the differences and similarities between the distributions of the three taxa reported within the political boundaries of Sonora.

The key ecological factors determining most insect distributions are those related to trophic relationships and microhabitat. In the case of butterflies, trophic associations and distributions are clearly linked because butterflies are where their host plants are, at least during larval stages. In the present data set used, all of the 15 most widespread species (American distribution) are polyphagous and reported from a wide range of plant species. For example, *Achlyodes tamenund*, is found on the many species of the Rutaceae family including *Citrus spp.*, *Erynnis funeralis* is found on 13 genera of Leguminosae, and *Panoquina ocola* feeds on several genera of Poaceae, including rice and sugarcane. The only exception to the polyphagous habit of widespread species is *Copaeodes minima*, which is restricted to feeding as larvae on *Cynodon dactylon*, the widely cultivated Bermuda grass. Of the two Sonoran endemic species recorded here, their distribution, as well, is determined by the range of their larval host plant. Both are species of Hesperidae and are specific to species of Agavaceae of the Sonoran desert: *Agathymus aryxna* on *Agave palmeri* and *A. chrysantha* on *Agave schotti* (Scott 1986). Although the presence of adequate hosts plants is clearly not the only determinate of butterfly distributions (Dingle and others 2000), especially for the highly mobile adult stage, the effect of historical factors and ecological limitations on their host plants is the primary predictor of butterfly distribution.

Comparison of species composition of Papilionidae and Pieridae (fig. 2) among selected states of Mexico and Arizona had an expected separation between southern Mexican States of Oaxaca, Chiapas, and Veracruz with the northern states of Tamaulipas, Sonora and Arizona. The central State of Querétaro, although compiled from collections in the arid regions of the state, has more affinities to the south than north. The greater similarity of Papilionidae between Tamaulipas and Sonora, than Sonora with adjacent Arizona, was notable and probably reflects the increasing dominance of tropical plants as one goes further south in Sonora, as is found in southern Tamaulipas. The relative dissimilarity between the butterfly fauna of Sonora and Arizona (fig. 2) is also reported by Marshall and Liebherr (2000) between temperate and tropical adapted species of other faunal groups and plants. In the case of butterflies, this dissimilarity is probably because many tropical butterflies and their host plants (Felger and others 2001) reach their most northern distribution in the State of Sonora, particularly in the Sierra Madre Occidental, and these butterflies rarely reach the United States' border.

The distribution of species of Odonata are determined by the distribution of suitable aquatic habitats (Kalkman and others 2008), although like butterflies, they can be found far from immature habitats. Kalkman and others (2008) report that the Southwestern United States is a center of diversity and endemism of dragonflies but many species are wide-ranging, a pattern also found for species from northwestern

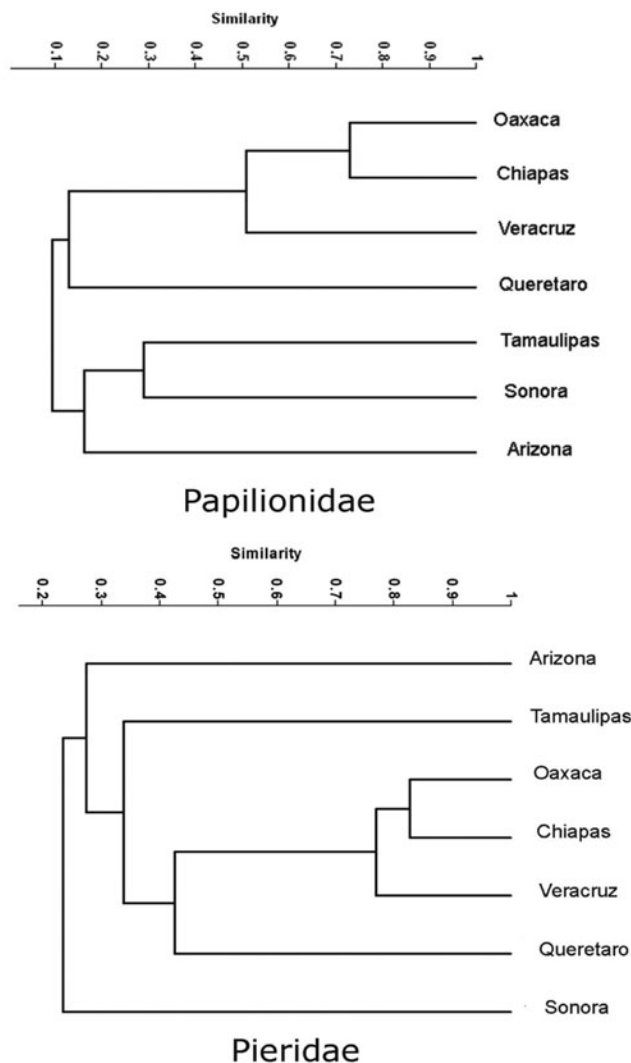


Figure 2—Cluster analysis of species richness of Papilionidae and Pieridae (Lepidoptera) from various states of Mexico using Jaccard's Index.

Mexico. Because of the highly developed flight capabilities of adults and the fact that both adults and nymphs are predaceous and feed on a wide variety of prey, it is easy to understand how many species can maintain widespread distributions. However, species with highly restricted distributions are more difficult to explain, partially because there is much to learn about microhabitat requirements of Odonata, and accurate population estimates are usually lacking (Abbott 2005). Also, lacking is an understanding of specific adaptations of Odonata to unpredictable, marked seasonality of aquatic habitats in tropical regions such as Sonora.

Ant species had the most restricted distributions of the taxa examined, with greater numbers of species restricted to the Sonoran Desert. The Sonora Desert has a unique climatic regime (Ives 1949; Ehleringer 1985), which apparently has persisted as a desert refuge throughout the Quaternary (Hewitt 2000). As foraging success and colony function of ants are tightly limited by temperature and humidity (Hölldobler and Wilson. 1990), the climatic conditions and persistence of the Sonoran desert ecosystem through time have apparently been conducive to the speciation and survival of ant species. Close to half of the ant species of Sonora had distributions throughout northern Mexico, particularly in states within the Chihuahuan desert, including Arizona and New Mexico, suggesting distributional limitations due to specialization in arid environments.

Further collection of the insect groups discussed here, as well as other taxa within the State of Sonora, will certainly improve our understanding of the complex and intriguing topic of the biogeographic affinities of Sonoran insects. Increased international cooperation between scientists in Mexico and the United States is necessary to coordinate future collection efforts and share systematic knowledge of the insects of Sonora, Mexico, and, specifically, their Sky Islands. Many specimens collected from Sonora are already present in collections that also need to be incorporated into present data bases. These efforts also need to be coordinated for all the surrounding states of Sinaloa, Chihuahua, and Baja California, which will lead to a more unified understanding of the natural history of the Northwestern Mexican-Southwestern United States region.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Preliminary Survey of Bee (Hymenoptera: Anthophila) Richness in the Northwestern Chihuahuan Desert

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Abstract—Museum records indicate that the peak number of bee species occurs around the Mediterranean Sea and in the warm desert areas of North America, whereas flowering plants are most diverse in the tropics. We examine this biogeographic pattern for the bee species known from a limited area of northeastern Chihuahuan Desert, Mexico/United States. This topographically complex area has been studied for more than 50 years for bees, which allows us to compare faunas in nearby areas that vary from low elevation desert scrub to high elevation montane forest. Our analysis indicates that bee diversity in this area is unusually high, and also that there is a poorly documented unique montane fauna.

Introduction

Bees (Hymenoptera, Anthophila) are a group of ca. 20,000 species worldwide (Ascher and Pickering 2012; Michener 2007), and the predominant pollinators in most terrestrial ecosystems. Yet, paradoxically, given their reliance on flowering plants, the literature and museum records suggest that bee species richness peaks in xeric, Mediterranean-climate areas far from the wet tropical areas where most groups, including flowering plants, reach their highest known species richness. Worldwide diversity of bee species is thought to be highest in xeric warm-temperate areas of the Western Hemisphere and around the eastern Mediterranean Sea in the Eastern Hemisphere (Grace, 2010), and to decrease in mesic environments and towards the tropics (Michener 1979, 2007). Local bee faunas in North America can be extremely diverse but appear to be particularly so in deserts of the southwestern United States and northwest Mexico (Ayala and others 1993; Michener 1979 table 1; Moldenke 1976). Of the roughly 3500 described bee species in North America north of Mexico, about 75% occur in the topographically diverse western United States. The most diverse bee faunas are reported for seasonally dry areas, including chaparral (and adjacent vegetation types) in Riverside California (439 species, Timberlake in Linsley 1958), sparse Sonoran Desert scrub in and around Palm Springs, California (more than 500 species, Timberlake, in Michener 1979), chaparral and other habitats in the inner Coast Ranges of central California (393 species, Messinger & Griswold 2002) and Great Basin Desert in Utah (334 species, Griswold and others 1997). The bee fauna in lowland subtropical deciduous forest in Chamela, Jalisco in western Mexico has intermediate diversity

(228 species, Ayala 1988). In contrast, numbers of bee species reported from mesic areas of eastern and central United States are 64 species in Miami, Florida (Graenicher 1930), 103 in Hattiesburg, Mississippi (Michener 1947), 169 in the Chicago, Illinois, area (Pearson 1933), 297 in Carlinville, Illinois (Robertson 1929), and 552 in the large and topographically extreme Boulder County, Colorado (Scott and others 2011).

Although the bee studies listed above suggest that there is high bee diversity in the xeric areas of western North America, these studies differ tremendously in the area sampled and duration over which collections were made. Large or topographically complex areas can have increased species richness due to greater numbers of habitats, greater area, or both (Rosenzweig 1995). Sampling that is limited temporally, for example from one part of the activity season or from only a few years, can greatly underestimate local bee diversity (Williams and others 2001). The purpose of this study is to examine known bee species richness for an unusually well-sampled area of the northwestern Chihuahuan Desert. This is a region of North America where bee diversity has been thought to be unusually high. One set of specimen records is associated with activity associated with the Southwestern Research Station of the American Museum of Natural History (AMNH). Numerous researchers, including J. G. Rozen, Jr. and others based at this station have collected and studied bees most years since the station was founded in 1955. For the past 13 years, massive collections from individuals based there have been made in association with the Bee Course on bee identification and biology that has been held at the Southwestern Research Station. A second set of specimens is from an ecological study of bee diversity that has been underway since 2000 south of the Southwestern Research Station along the United States-Mexico border in the San Bernardino Valley (Minckley 2008). Collections in this area were started initially to estimate bee species richness in this area using standardized methods, but have broadened in association with other projects (Minckley and Roulston 2006).

Lists of bee species from the two efforts described above are still increasing as additional species are collected and identified (or recognized as new). Despite the preliminary status of the data, a compilation

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Table 1—Number of bee species, number (and proportion) of species and collection phenology recorded from six Chihuahuan Desert localities. Also shown is the year each locality was first sampled and the numbers of years and days bees were made.

	Number species	Number and proportion unique species	First year sampled	Total years sampled	Total days sampled
San Bernardino Valley	435	223 (0.51)	2000	11	516
Douglas	141	3 (0.02)	1943	41	116
Apache to Rodeo	144	12 (0.08)	1956	39	111
Willcox	155	15 (0.09)	1952	46	150
Apache southwest	129	6 (0.05)	1956	37	134
Upper montane	104	15 (0.14)	1950	43	116

of records assembled to date is useful because sampling from the region is now unusually large in scope (duration and intensity) and very large numbers of specimens have been identified to species and databased. Furthermore, many bee species reach the extreme limits of their distribution in this area (Burquez 1997; Minckley and Reyes 1996). Here we compile and compare lists of known species from six well-sampled localities to gain some insight into (1) the number of species in this area, (2) the differences in the faunas in desert, mid elevation and upper montane areas, and (3) the future work needed for a fuller understanding of bee species richness in this region and its implications for assessing larger-scale patterns.

Methods

A total of 65,485 bee specimens were included in this study; all from Cochise County in southeastern Arizona, United States and extreme northeastern Sonora, Mexico. We limited the species included to specimens from six localities (five in Cochise County well represented in the AMNH database and the San Bernardino Valley that have been unusually well-sampled. Thus, other bee species known from this area (i.e. Cochise County, Arizona, and adjacent northernmost Mexico) are not considered in this study because they either do not occur or have yet to be recorded from these localities. These localities demarcate an area approximately 5700 km² that is topographically complex, ranging in elevation from 1100 to 2895 m. Vegetation is mainly Chihuahuan Desert scrub at the lowest elevations and shifts through desert grassland, oak woodland, pine-oak, and coniferous forest at progressively higher elevations (Brown 1994). Collections were also made at unusual, more localized habitats including limestone outcrops in the San Bernardino Valley and sand dunes near Willcox, Arizona.

For brevity, hereafter we refer to those specimen records that are being assembled as part of a larger collaborative effort to document information from specimens housed in a number of North American museums as the AMNH specimens or database (see acknowledgements)

Localities

Following is a brief description of each of the six localities.

San Bernardino Valley, Arizona/Sonora (31° 20' N, 109° 15' W, 1134m)—This is the headwaters of the Rio Yaqui in southeastern Arizona, United States that runs south across the Mexico-United States border into northeastern Sonora, Mexico (31° 20' N, 109° 15' W). Most collections in the United States were made in the San Bernardino National Wildlife Refuge, a 900-hectare preserve in southeastern

Cochise County, Arizona. In Mexico, most collections were made at Rancho San Bernardino, 30 km east of Agua Prieta, Municipio of Agua Prieta, Sonora, Mexico. Elevation ranges from 1100 to 1340 m. Minckley (2008) provides a detailed description of the climate and area. Vegetation is a mix of creosote bush (*Larrea tridentata* (Sessé & Moc. ex DC.), Coville and velvet mesquite (*Prosopis velutina* Wooton) dominated Chihuahuan Desert scrub in the lowest elevations, and Chihuahuan Desert grasslands (*sensu* Brown 1994) at the higher elevations (see also Minckley, *Trajectory and Rate of Desert Vegetation Response Following Cattle Removal*, this volume).

Unlike all other localities, the San Bernardino Valley study extensively used pan traps in addition to net sampling, the method used to obtain the vast majority of collections at other localities.

Douglas, Cochise County, Arizona (31° 21' N, 109° 27' W, 1220m)—Most collections in this area are from “1 mile east of Douglas” at 1300 m elevation. Specimens with label data from within 6 km of Douglas in any direction were included in this study because vegetation in this area is desert scrub similar to that described above for the lower elevations of the San Bernardino Valley. Although only 25 km due west of the San Bernardino Valley, this area is in the Sulfur Springs Valley and separated from the San Bernardino Valley by the southern end of the Pedregosa Mountains.

Cazier and Linsley (1963) provide a description of the site “1 mile east of Douglas” and the late-summer vegetation. Since that description, some of this area has been developed. Collections span from 1943 to the present.

Apache, Cochise County, Arizona (31° 41' N, 109° 08' W, 1336 m)—Collections included in the area are along Highway 80 that runs along the north-flowing San Simon River in the San Simon Valley. Specimens were included if label data indicated they were between 2 km south of Apache to 2 km south of Rodeo, Hidalgo County, New Mexico (23 km in total). This area is primarily desert scrub similar to that described for the lower elevations of the San Bernardino Valley (see above). Apache, Arizona, is 60 km north of the San Bernardino Valley. They are separated by grasslands on the San Bernardino volcanic field.

This locality along Highway 80 is a primary corridor between the Southwestern Research Station and Douglas, the nearest city, and numerous biological studies of bees describe this area (Danforth 1989, 1991, 1999; Hurd and Linsley 1975; Hurd, LaBerge and Linsley 1980). Collections span 1956-2011.

Willcox, Cochise County, Arizona (32° 11' N, 109° 44' W, 1290m)—This area is along the northeast boundary of the Willcox playa, a closed basin (i.e. lacking external drainage) and remnant of the Pluvial Lake Cochise that had been a much larger and deeper lake at its maximum

13,750–13,400 yr B.P. (Waters 1989). The area has typical vegetation of the desert scrub community in addition to other, less common plant species associated with the sand dunes (*Oenothera* spp., *Psoralea scoparius* (A. Gray) Rydb., *Euphorbia* spp., *Nama demissum* A. Gray, and *Wislizenia refracta* Engelm.), and many notable bees (Rozen 1987, 1992; Rozen and Rozen 1986).

The most common locality on labels from this area references “4 mi east of Willcox.” For the species list included here we also included sites in the vicinity of Willcox that are bounded by Interstate 10 on the north and by the Willcox Playa on the south. This locality is the furthest north of any other in this study. It is ca. 110 km NNW of the San Bernardino Valley on the opposite side of the Chiricahua Mountains.

Southwest of Apache, Cochise County, Arizona: (31° 34' N, 109° 15' W, 1400m)—This locality is also along Hwy 80 and was included because it is the best-collected area in the Chihuahuan Desert grassland (i.e. at lower elevations than oak and pine woodland) and because it has a rich and distinctive fauna (Rozen 1989, 1992). Most labels refer to “[13, 13.5, or] 14 miles southwest of Apache,” a roadside site along a railway line among cinder cones. It is just north of a riparian area along Silver Creek, a stream that drains a large area of the southern Chiricahua Mountains. Higher water availability and cold air drainage in habitats such as these enables some plant species to occur at lower elevations than they do normally (Shreve 1922), which may influence where bees occur.

Upper Chiricahua Mountains, Cochise County, Arizona (31° 51' N, 109° 17' W, 2700m)—Several roads climb to the oak-pine and pine forest found on the upper elevations of the Chiricahua Mountains. We included any bee species in this mountain range that had been collected over 1580 m, where oak, oak-pine, or coniferous are the dominant vegetation type. By using this elevation as a cutoff we excluded a very large set of specimens collected at the Southwestern Research Station where disturbance associated with building construction has created an unusually open and more xeric habitat allowing bees typical of desert scrub to occur above their usual range.

Bee Species Lists

Lists were limited to specimens that were identified to genus and species. This excluded a number of species from the San Bernardino Valley study that are now designated as morphospecies.

A complete list of the bee species at each of the six localities will be published in the journal Checklist (www.checklist.org.br/) and made available as a Research Species list in Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org). All specimens records in the AMNH Bee Database and associated databases are available at Discover Life (Schuh and others 2010).

We compared the similarities of bee species lists rather than using statistical approaches based on incidence that species were collected or species abundance (Gotelli and Colwell 2001) because of the differences in how species lists were assembled at the AMNH and in the San Bernardino Valley study. Records of species from five sites (Douglas, Willcox, Apache-Rodeo, 14 miles southwest of Apache, and Upper Chiricahua Mountains) represented in the AMNH database is ongoing and does not presently include comprehensive records of all individuals of each species, or the number of times they were collected at each site. Also, retrospective data capture from information on specimen labels is from identified material, mostly housed in the AMNH and is in progress. In contrast, all material from every collec-

tion made in the San Bernardino Valley is recorded in a database but species-level identifications of some specimens remain to be verified.

Results

Localities

The number of bee species at the six localities differed from 435 in the San Bernardino Valley to 104 species in the high elevations of the Chiricahua Mountains (table 1, fig. 1). The five localities in the AMNH database have much closer numbers of species among themselves than any have to the San Bernardino Valley.

Approximately 55% of all species (300 of 540 species), were recorded at one locality and very few were extremely widespread (fig. 2), consistent with high bee richness in our study area. The proportion of unique bee species reported only from the San Bernardino Valley (52%) was far greater than found in the other localities (fig. 1). In

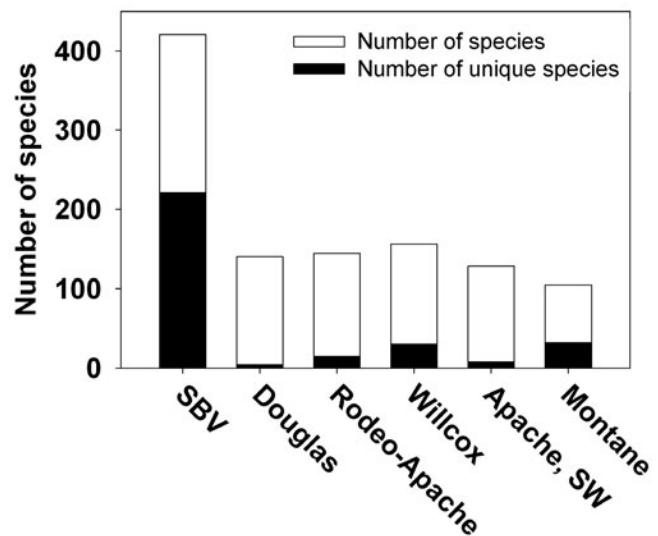


Figure 1—Bee species recorded from six localities in the northwestern Chihuahuan Desert. Locality designations used here are the same as in the text except for SBV = San Bernardino Valley. Numbers of species that are found only at the locality are indicated on the bar in black.

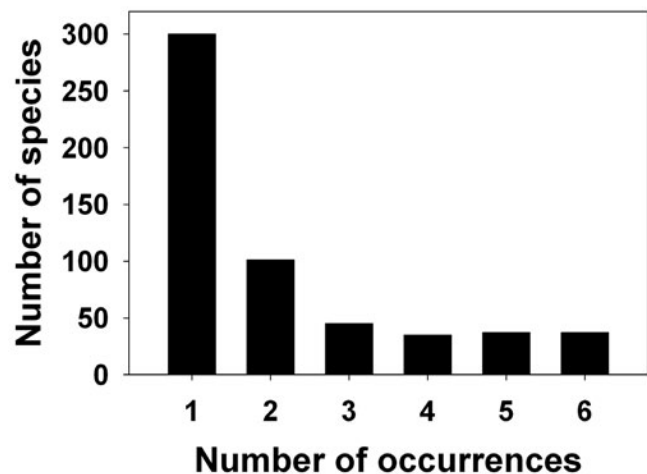


Figure 2—Number of localities where bee species were recorded. Most species occur at one locality and very few are extremely widespread.

descending order, the proportion of unique species at the other localities were montane (30%, 32 of 105 species); Willcox (19%, 30 of 156 species); between Rodeo, New Mexico, and Apache, Arizona, on Highway 80 (8%, 15 of 144 species); southwest of Apache, Arizona (6%, 8 of 128 species); and Douglas, Arizona (3%, 4 of 120 species).

Vegetation Associations

The three major vegetation types represented in the localities were desert scrub, oak-grassland, and oak pine or coniferous forest. By far, most bee species were found in one vegetation type (N = 386), none were reported from two, and few were found in all three (N = 44).

The number of unique species recorded from the desert scrub localities was far greater (N = 390) than reported from grassland (N = 34) or upper montane (N = 57) (fig. 3). However, the proportion of unique species was high and similar in the desert (78%) and the upper montane (72%) habitats, and was intermediate in the transition zone of Chihuahuan grassland and oak (41%).

Collecting Effort

Collections in the San Bernardino Valley span the fewest years of any locality but amount to four to five times more collection days than at other localities (table 1). The other five localities range from 111 to 150 collection days (table 1). The proportion of all collections represented by the AMNH specimens included in this study and the San Bernardino Valley are shown in figure 4. AMNH collections are biased towards August (particularly mid-late August), when the Bee Course is offered (see Introduction) and fewer collections are in early summer and spring. In contrast, San Bernardino Valley collections were made in most months, except for a deficit towards the end of the bee activity season (late September and October).

Discussion

In total, 540 species are represented in this study. In the western United States, a four-year study reported 656 bee species and morpho-

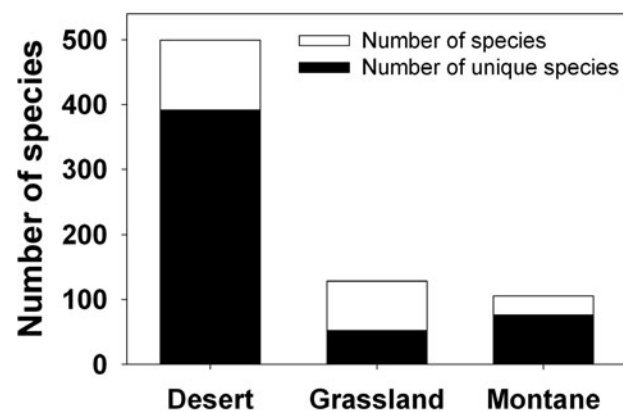


Figure 3—Bee species recorded from three primary vegetation habitats in the northwestern Chihuahuan Desert. Locality designations used here are the same as in the text except for Montane = Upper Montane. Numbers of unique species (recorded from one locality) are indicated on the bar in black.

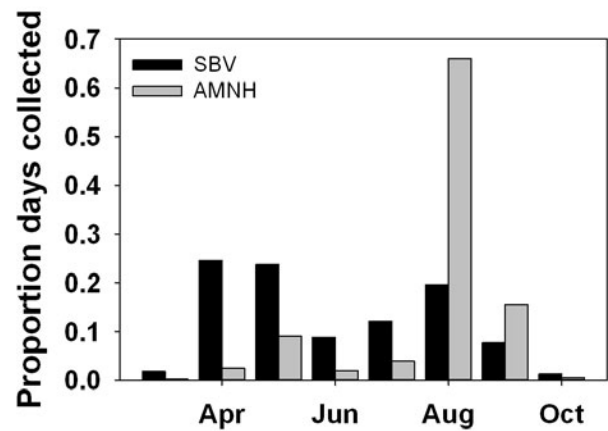


Figure 4—The phenology of collections made at San Bernardino Valley (SBV) and the other five localities (AMNH specimens) expressed as a proportion. Of note, is the difference in collection effort in March and April.

species in Grand Staircase National Monument, Utah (Griswold and others 1997). The Utah study included collections made throughout the monument. The similar number of bee species in that study to just six localities included here from the northeastern Chihuahuan Desert hints at high bee diversity. The San Bernardino Valley, where the greatest number of bee species was recorded from the six localities, was where the most collections were made across a wider date range and where pan traps were used extensively in addition to nets. Pan traps are known to sample a different portion of the bee fauna than other methods (Droege and others 2009; Rouston and others 2007). Thus, more data are needed to establish if the bee diversity in the San Bernardino Valley is unusual or collecting bias.

Few bee species are widespread and many are localized (N = 44 in three vegetation types, none in two, and 386 in one). The variation in species number among localities reflects both statistical issues with these data and underlying biological pattern. Statistical biases arise from the way the species lists are being assembled at the AMNH. First, database information on AMNH specimens is ongoing making statistical estimates of species richness or species turnover not possible. Second, some differences can be attributed to where taxonomic expertise of specific bee groups has been focused. *Tripeolus*, *Lastioglossum (Dialictus)*, and *Osmia* have been curated more thoroughly from the San Bernardino Valley than in the AMNH specimens whereas *Andrena*, *Pseudopanurgus*, and *Protandrenini* were more thoroughly curated at the AMNH than those same taxa from the San Bernardino Valley. Finally, biases in the timing of collections also confound these types of analyses. The proportion of spring collections is far greater in the San Bernardino Valley than in collections made at the other localities (fig. 4). Most bee species in the warm deserts of North America have short flight seasons and are solitary, particularly those oligolectic species that visit one or a few host plants for pollen. Approximately 35% of pollen-collecting bee species (excluding *cleptoparasitic* species) are oligolectic (Minckley 2008). In solitary bee faunas, the effect of sampling effort should be pronounced, as will be the presence of host plants required by those species that are oligolectic. Many of the spring-active bee species found in the San Bernardino Valley samples are not represented in the AMNH database.

There are many biological reasons why bee species composition differed among sites. First, rarity in desert bees is pervasive; collections

that differ in distance and time have all found the proportion of rare (i.e. rarely-detected) species in deserts is high (Minckley and others 1994; Williams and others 2001). Second, in some cases, rare bees or those with limited local distributions only occur where their host plant is found. Two pollen specialist bee species, *Calliopsis macswaini* (Rozen 1958) and *Perdita wislizeniae* (Timberlake 1964), were found only at the locality their host plant, *Wislenzia refracta*, occurs in the sand dunes near Willcox, and the former is absent from recent samples. The extremely rare bee, *Macrotera parkeri* (Timberlake 1980), is a cactus specialist species known previously only from Austin, Texas, (two individuals) and Puebla, Mexico (one specimen) (Danforth 1996). In the San Bernardino Valley it visits the cactus, *Coryphantha robbisorum* (W. Earle) A.D. Zimmerman, a limestone soil endemic. Finally, beta-diversity is expected to be exceptional given that this study is focused at an intersection of major North American biomes where many bee species reach their range limits (Minckley and Reyes 1996). Two notable examples of species in this dataset at the northernmost point of collection are *Eulonchopria punctatissima* Michener, the northernmost-occurring species of Neopasiphaeinae (formerly included in Paracolletinae or Colletinae sensu lato) that visits species of *Acacia* with white flowers (*Acacia angustissima* (Mill.) Kuntze and *A. millefolia* S. Watson) and was found in the past but not in recent years along Highway 80 in Cochise County, and what is likely to be a transient individual of *Agapostemon nasutus* Smith, 1853, a widespread Neotropical species known in the San Bernardino Valley from only a single female (Mexico: Sonora, 30 km E. Agua Prieta, 29 May 2007, on *Sphaeralcea angustifolia*, RL Minckley [coll.]).

Identifying why most bee species in this study are geographically limited or rare is not easily explained. Many species are similar to the pollen specialist bee *Lasioglossum lusorium* (Cresson 1872) that has been recorded in this study only near Willcox, Arizona, but has a much broader distribution (southern Canada, California, central Mexico Kansas) (McGinley 2003).

The most notable findings of this preliminary study are the low species overlap in the desert and upper montane habitats in this limited area, and the high proportion of unique bee species found in these same habitats. The Sky Island region above 2300 m elevation are the northernmost known localities for the Neotropical genus (*Mexalictus*) (Eickwort 1978), known in the Chiricahua Mountains only from a recent collection by JSA (new information) and the southernmost known localities of two species with Holarctic affinities: *Lasioglossum boreale* (Svensson and others 1977) and *L. dasiphorae* (Cockerell 1907) (Packer and Taylor 1997). In Mexico, in the northern Sierra Madre Occidental at Yécora, one specimen of a stingless bee (*Partamona bilineata*) (Say 1837) was collected in pine-oak forest, which represents the most northern record of the tribe Meliponini in North America (Minckley and Reyes 1996). Ten tropical bee species have been rarely collected from this area and all but one of these occurred in oak woodlands or pine-oak forests of Sky Islands along the Arizona-Mexico border (Minckley and Reyes 1996). Recent collections from the oak woodland in the Sierra San Luis, just 3 km south of the United States-Mexico border (31° 17' N, 108° 47' W), have yielded two new species of spring-active species of *Osmia* (Rightmyer and Griswold 2010). A new species of *Lasioglossum* (*L. viridipetrellum* Gibbs 2009) is known only from Sky Islands above 2200 m in southeast Arizona (Gibbs 2009), as is an undescribed species allied to *L. (D.) ruidosense* (J. Gibbs, pers. comm.). These recent descriptions, in addition to the study reported here, suggest there is greater bee endemism in the upper montane habitats of these areas than has been appreciated. Given the distinctiveness of this bee fauna, the predicted increasing frequency of fires (Westerling and others 2007), and effects of climate

change (International Panel on Climate Change 2007) on these upper elevation habitats, further documentation and sustained monitoring of this bee fauna is of particular and pressing interest.

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Introduction to the Arizona Sky Island Arthropod Project (ASAP): Systematics, Biogeography, Ecology, and Population Genetics of Arthropods of the Madrean Sky Islands

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Abstract—The Arizona Sky Island Arthropod Project (ASAP) is a new multi-disciplinary research program at the University of Arizona that combines systematics, biogeography, ecology, and population genetics to study origins and patterns of arthropod diversity along elevation gradients and among mountain ranges in the Madrean Sky Island Region. Arthropods represent taxonomically and ecologically diverse organisms that drive key ecosystem processes in this mountain archipelago. Using data from museum specimens and specimens we obtain during long-term collecting and monitoring programs, ASAP will document arthropod species across Arizona's Sky Islands to address a number of fundamental questions about arthropods of this region. Baseline data will be used to determine climatic boundaries for target species, which will then be integrated with climatological models to predict future changes in arthropod communities and distributions in the wake of rapid climate change. ASAP also makes use of the natural laboratory provided by the Sky Islands to investigate ecological and genetic factors that influence diversification and patterns of community assembly. Here, we introduce the project, outline overarching goals, and describe preliminary data from the first year of sampling ground-dwelling beetles and ants in the Santa Catalina Mountains.

Introduction

The outcome of millions of years of mountain building, the 7250 km long North American Cordillera or “Western Cordillera” runs from northern Alaska to southern Mexico. This great cordillera, the spine of the North American continent, has but one break, a low saddle between the Rocky Mountains/Colorado Plateau and the Sierra Madre Occidental, which forms a biogeographic barrier between the montane biotas of temperate and tropical North America (Heald 1951; Marshall 1957; McLaughlin 1986, 1995; Warshall 1995; Bowers and McLaughlin 1996). The Madrean Sky Islands are the isolated mountain ranges that span this Cordilleran Gap. Sometimes called the “Madrean Province” or “Madrean Archipelago,” these mountain ranges are a unique subset of the Basin and Range Province and cover about 168,400 sq. km. (~77,700 sq. km. in the United States).

Although many of the plants and some of the animals of the Sky Island Region have been well studied, little is known about the

arthropods (e.g., insects, isopods, millipedes, mites, spiders, scorpions, etc.). Yet, these ecologically diverse organisms drive key ecosystem processes such as pollination, litter decomposition, nutrient recycling, and soil aeration, and they are important food for reptiles, birds, and small mammals. Despite their ecological importance, arthropods are poorly known because most are small, live in opaque habitats where observation is difficult, and few taxonomists have specialized on these groups in the Sky Island Region (Behan-Pelletier and Newton 1999). Using data from museum specimens and specimens we obtain during long-term collecting and monitoring programs, ASAP will document arthropod species across Arizona's Sky Islands to address a number of fundamental questions about the arthropods of this region, including the following:

1. What arthropods inhabit Arizona's Sky Islands? How are these species distributed within the region?

One of the greatest resources for this project is the University of Arizona Insect Collection (UAIC), which contains over two million research specimens, 83% of which are identified to species level, mostly from the Sonoran Desert Region, its Sky Islands, and adjacent biomes of northwestern Mexico. In the last few decades, UAIC researchers have participated in long-term surveys in the Santa Catalina, Baboquivari, Mule, Huachuca, Chiricahua, and Waterman Mountains, and other montane areas; as well as in impact studies of the Mt. Graham telescope site in the Pinaleno Mountains and the Rosemont Mine site in the Santa Rita Mountains. Locality data from UAIC specimens will

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

be incorporated into a specimen-level database for the ASAP Project; this database also will be networked with other arthropod museums in the southwestern United States.

Species diversity of the Sky Island Region is also being documented through a series of collecting expeditions. Throughout the project, we will conduct surveys of the arthropod fauna using a variety of collecting methods including light traps, malaise traps, pitfall traps, and hand collecting methods. All specimens from the ASAP project will be accessioned into the UAIC. They will be identified to species, and specimen-level data will be maintained in the UAIC specimen-level database. Representatives of many species will be preserved in a frozen tissue collection in -20°C freezers and all other specimens collected will be mounted on points/pins and deposited in the UAIC pinned collection or preserved in 80% ethyl alcohol and archived for future work.

2. What are the biogeographic affiliations and phylogeographic relationships of the Sky Island arthropods? Have arthropods diversified or radiated within the Sky Island Region?

The distribution and/or elevation of Madrean Sky Island species has repeatedly shifted as a result of cyclical climate changes during the Quaternary (Martin 1963; Betancourt and others 1990; Van Devender and Spaulding 1990; Davis and Brown 1988; Van Devender 2002). Several studies have focused on the biogeography of species in the Arizona Sky Island Region including plants, arthropods, birds, lizards, and mammals (Brown 1971; Downie 2004; Linhart and Permolli 1994; McCord 1995; Sullivan 1994; Slentz and others 1999; Barber 1999a,b; Maddison and McMahon 2000; Masta 2000; Boyd 2002; Smith and Farrell 2005a,b; McCormack and others 2008; Tennesen and Zamudio 2008; Ober and others 2011). Most of these studies have documented significant morphological variation or genetic structure among separate subspecies or populations endemic to different mountain ranges within the Sky Island Region. However, none of these studies have used broad taxonomic sampling in the context of phylogeographic analyses to look at the geographic origin of the Sky Island fauna. In ASAP, we will infer the evolutionary relationships and estimate divergence times using molecular sequence data from fast-evolving mitochondrial and nuclear genes. From these data, we will reconstruct the evolutionary and biogeographic history of the Sky Island arthropod species, and look for emergent patterns that may reveal phylogeographic origins of the fauna and radiations of species groups among the mountain ranges.

3. What are the over-arching drivers that structure arthropod communities in the Sky Islands?

The spatial arrangement of similar, isolated habitats repeated on numerous mountain ranges in the Sky Island Region provides natural replication for ecological studies. We will utilize the natural laboratory provided by the Sky Islands to investigate ecological and genetic factors that influence diversification and patterns of community assembly. In particular we will address the following questions: (1) How are species distributed along elevational gradients? (2) Are the patterns correlated with plant communities/biomes, soil pH, precipitation, temperature, and/or humidity? (3) Do high elevation arthropod communities differ in species composition between isolated mountain ranges? (4) Do larger tracks of woodland or forest harbor a greater diversity of arthropods? To address these questions, ASAP makes the first effort to extensively and quantitatively sample the arthropod fauna for a broad swath of the Madrean Sky Islands. It will provide baseline data on the abundance, diversity, and community structure along elevation gradients throughout the region for this taxonomically and ecologically diverse group of organisms.

4. How might montane arthropod communities respond to rapidly changing climate conditions?

The Madrean Sky Islands provide a model system for investigating the effects of rapidly changing climate on the biodiversity of isolated landscapes. Sky Islands show a stronger effect of isolation than other types of isolated habitats (Watling and Donnelly 2006). Effects of climate change are already evident here (increased fire, drought, pest outbreaks, and invasive species). Additional temperature increases of as little as a few degrees could push Sky Island plant and arthropod species/communities to higher elevations, reducing their habitable area and potentially causing local extinctions of endemic taxa and evolutionarily unique lineages. Projections from global climate models suggest that temperatures in the Southwest will increase by $3\text{--}6^{\circ}\text{C}$ over the next century (Kupfer and others 2005; Gutzler and Robbins 2010; Overpeck and Udall 2010; Dominguez and others 2010; IPCC 2001, 2007; CLIMAS 2012). Predictions of whether precipitation will increase or decrease are still in conflict, and confidence in precipitation estimates is low at this time. Models used to examine how plant communities may respond to projected climate change indicate that increases in temperature will lead to upslope movement of communities, leading to an increased area of Desertscrub (western Sky Islands) or Desert Grassland (eastern Sky Islands) and a decrease in the area occupied by Mixed Conifer Forest, the biome situated at the top of the highest mountains (Kupfer and others 2005). However, increased precipitation might slow upslope movements by lessening growth constraints imposed by arid conditions. If climates continue to warm as projected, species will need to shift their present distributions or adapt to warmer conditions rapidly.

Anthropogenic activities are contributing to increased levels of atmospheric CO_2 and these higher levels are leading to increased global temperatures and changes in the hydrologic cycle, thus causing or contributing to climate change (IPCC 2001, 2007). Several reviews have highlighted that little is known about the current and predicted responses to climate change for most arthropod groups (Coviella and Trumble 1999; Hughes 2003). Because important ecosystem processes, such as litter decomposition and nutrient cycling, are driven by ground-dwelling arthropods (Powers and others 2009; Yang and Chen 2009), ecosystem responses and subsequent feedbacks to atmospheric and climate changes may depend on how soil arthropod communities respond to these perturbations (e.g., reduced decomposition rates will decrease feedbacks to global carbon (C) input, while increased decomposition rates will increase feedbacks to the C cycle; Bardgett and others 2008). As such, understanding the response of these species and communities to climate change is critical if we are to predict how such perturbations are going to alter both biodiversity and the functioning of ecosystems.

While natural communities may be able to adapt to changing climates to some extent, via shifts in the distribution of their local or geographic ranges, paleontological data suggest that communities do not respond to climate change as entities (Coope 1995; Jablonski and Sepkoski 1996). Rather, species responses tend to be idiosyncratic, resulting in the development of new assemblages and associations (Graham and Grimm 1990; Voight and others 2003). These results underscore the need for field-based inventories to better understand current diversity and distribution patterns, which in turn establishes a baseline for future comparisons and ecological studies to track how species and communities respond to future climate change in the Southwest.

We will use data acquired from our own collecting and from specimens housed in museum collections including the UAIC to determine climatic boundaries for target species; species-specific boundaries

will then be integrated with climatological models to predict changes in arthropod communities and distributions in the wake of potential rapid climate change. To date, the scientific community knows almost nothing about how arthropod species and communities will respond to climate change. But because changes in both species composition and abundances of arthropods can influence important ecosystem processes, it is vital to understand how arthropods species and communities will respond to climate change and how arthropods influence ecosystem processes. Additionally, because climate change is predicted to lead to a widespread reorganization of species and community patterns, it is important to document the biogeography of Sky Island arthropod species now, to determine patterns of endemism and identify species at risk of extinction.

The ASAP project will monitor distributions of Sky Island arthropod species over the next 20–30 years to see if there are detectable shifts in species distributions as climate changes. We will use ecological niche models and phylogeographic analyses in combination to assess how arthropods have responded to past changes in climate by shifting distributions and/or adapting in situ, which in turn will help us predict how species will likely respond to increasing isolation and future climate change. Ultimately, we aim to identify species in the Sky Island Region that might be at risk of extirpation or extinction as the Southwest warms, and to identify locations of refugia from past glaciation events that may be areas of high allelic diversity that merit conservation attention. We further predict that effects of climate change may be seen in this region of the country and on these isolated mountains before most other areas, and that by studying the effects of climate change here we can make better predictions as to what will happen elsewhere later in time.

Purpose of This Paper

The purpose of this paper is to describe the study system of the ASAP, including our concept of the Sky Island Region and its biomes, and to present preliminary data derived from our collections in the Santa Catalina Mountains during the first year of the project. In the initial phase of the project we are documenting the ground-dwelling arthropods of the Santa Catalinas, and the first year's sampling (2011) has been completed. The project will be expanded to other ranges in southern Arizona, and eventually to selected ranges in Mexico and to other arthropods (not just ground-dwelling taxa). Data collected in early years of the project will provide a baseline for future/continuing surveys designed to elucidate how populations, species, and communities change as climate changes in the Southwest.

Biogeographic Parameters of the Study

Boundaries and Concept of the Sky Island Region—When the term “Madrean Sky Islands” was first coined in the 1950s, it referred to those ranges possessing strong shared elements with the Sierra Madre Occidental (the “Madrean” flora). In fact, the term “Madrean Sky Islands” is not a perfect descriptor of the region, because many northern (e.g., Rocky Mountain or Petran) (Brown and others 1979; Brown 1994) species reach their southernmost range limits here, just as many southern (e.g., Madrean) species reach their northernmost range limits in this region. Although we are not suggesting a name change here, conceptually it might be more accurate to think of these mountain ranges collectively as “Cordilleran Gap Sky Islands” and for the ASAP project we broaden the definition of the Madrean Sky Islands to include all ~65 of the isolated mountain ranges spanning the Cordilleran Gap (that are high enough to have Oak Woodlands)

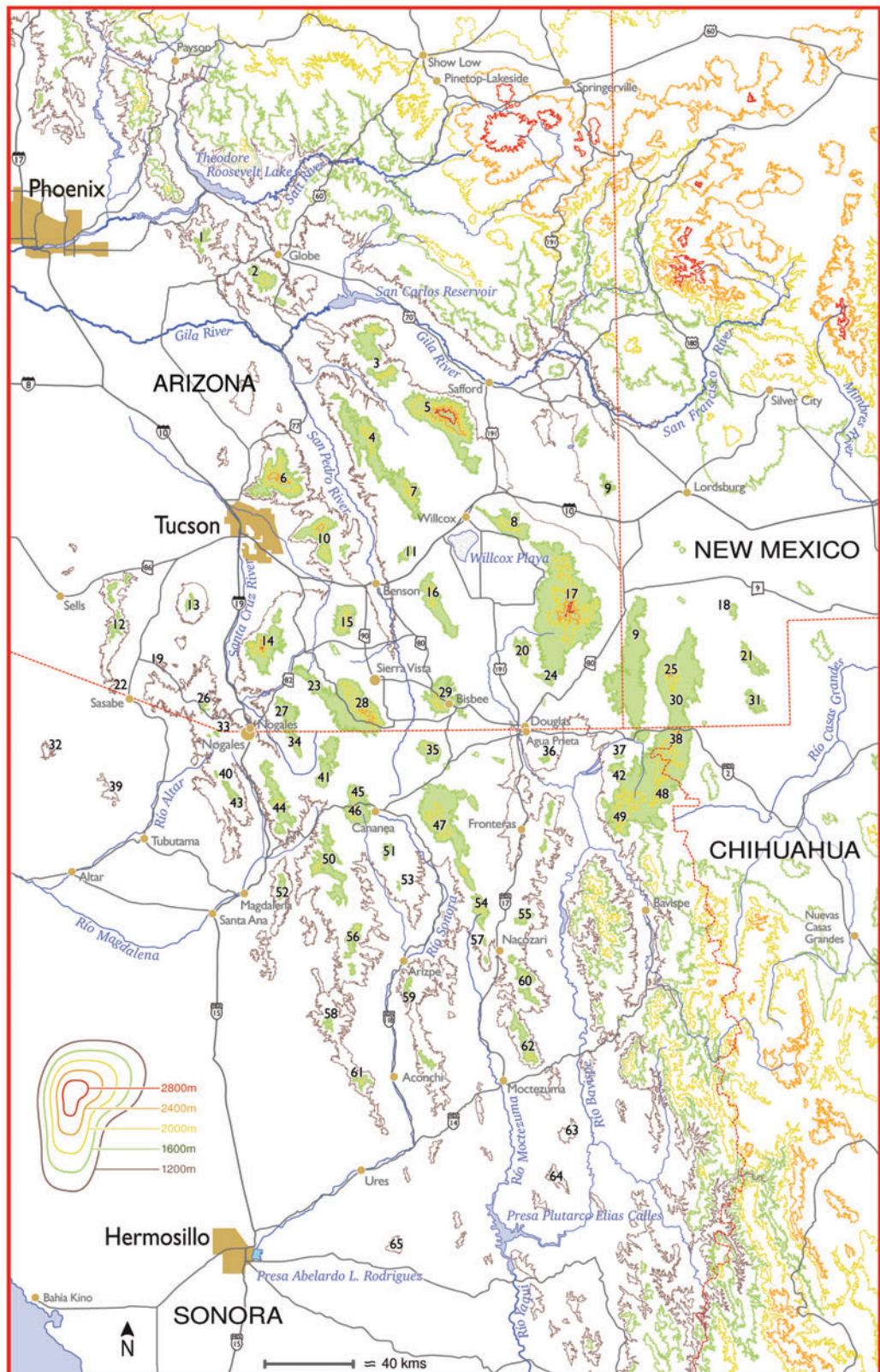
regardless of the degree of shared Madrean flora (fig. 1). We, therefore, include the northern Pinal and Superstition Mountains (Arizona) and the eastern Big and Little Hatchet and Alamo Hueco Mountains (New Mexico), which are traditionally not included on maps of the Madrean Sky Islands. We define the northern boundary of the Madrean Sky Island Region as the Salt River Valley; north of this lie the Mazatzal and Bradshaw Mountains, and other ranges of Arizona's Transition Zone that grade into the base of the escarpment of the Colorado Plateau's Mogollon Rim. The southernmost limit of the Sky Island Region is somewhat arbitrarily set at 29° N latitude (about the latitude of Hermosillo, Sonora). So, the northernmost Sky Islands are the Pinals and Superstitions; the westernmost Sky Islands are Sierra el Humo (in Sonora) and the Baboquivari Mountains (in Arizona); the easternmost are the Alamo Hueco and Big Hatchet Mountains of New Mexico; and the southernmost Sky Island is the Sierra Mazatán 70 km east of Hermosillo, Sonora.

Nearly all of the Madrean Sky Islands exceed 1525 m in elevation, or if falling short of that, they are connected by woodland habitat to an adjacent higher range and thus form part of a Sky Island complex. The Sierra el Humo reaches an elevation of 1650 m and has ~1036 ha of Oak Woodland (Flesch and Hahn 2005). Two small ranges to the west of Sierra el Humo have oak patches, but they do not exceed 1370 m elevation and do not have sizeable Oak Woodlands (Sierra El Cobre, 1350 m; Sierra El Duranzo, 1210 m). The Sierra Mazatán reaches only 1545 m, but supports a large area of Oak Woodland (~3626 ha, with five oak species) at its highest elevations, and it is surrounded by a “sea” of foothills thornscrub (Flesch and Hahn 2005; Dimmitt and others 2011).

The northernmost Sky Island ranges (the Pinal and Superstition Mountains) largely lack common Madrean species such as the silverleaf oak (*Quercus hypoleucoides*) that is so common in more southern ranges of Arizona. Instead, they harbor woodland of northern species such as Gambel oak (*Quercus gambelii*) the only winter-deciduous oak in the Sky Island Region, and Palmer oak (*Quercus palmeri*). The Pinals, which reach over 2380 m in elevation, support a large Petran Montane Pine Forest, surrounded by well-developed Oak Woodlands that connect to the woodlands of the Superstitions, the latter having only a few patches of ponderosa pine (the highest peak in the Superstitions is 1900 m).

In addition to these 65 ranges (fig. 1), several other small ranges in Mexico are apparently high enough to support Oak Woodlands, notably a few east of the Sierra Mazatán. However, plant data for these ranges are too sparse to draw firm conclusions at this time. We do not consider ranges with only scattered oak patches but lacking true Oak Woodland— such as Arizona's Tucson Mountains (Wasson Peak, 1429 m)— to be Sky Islands. Similarly, many of the small mountains in Sonora, west of the Sierra Madre Occidental, are high enough to support scattered patches of oaks, especially on their north-facing slopes (e.g., Sierra Cucurpe), but in general these are not large or contiguous *encinals* (Oak Woodlands). To the east, we include all of the ranges of appropriate elevation and isolation west of the Continental Divide, plus three east of the divide (Big and Little Hatchets and Alamo Hueco in New Mexico). Some authors have included the far eastern Cedar Mountains of New Mexico and others have included the Sierra San Javier, 130 km east-southeast of Hermosillo. Although included on some Sky Island maps, we do not include Sonora's huge Sierra el Tigre mountain complex (i.e., Sierras El Tigre, San Diego, el Oso, and los Pilaes de Teras) because the woodlands of those ranges connect to the Sierra Madre Occidental south of Huachinera (via the Mesa Los Tabachines, Sierra El Gato, and Sierra Los Tules), which connect to the Sierras at elevations over 1525 m, effectively making the Sierra El Tigre complex a “woodlands

- 1 Superstition Mountains
- 2 Pinal Mountains
- 3 Santa Teresa Mountains
- 4 Galiuro Mountains
- 5 Pinaléño Mountains
- 6 Santa Catalina Mountains
- 7 Winchester Mountains
- 8 Dos Cabezas Mountains
- 9 Peloncillo Mountains
- 10 Rincon Mountains
- 11 Little Dagoon Mountains
- 12 Baboquivari Mountains
- 13 Sierrita Mountains
- 14 Santa Rita Mountains
- 15 Whetstone Mountains
- 16 Dragon Mountains
- 17 Chiricahua Mountains
- 18 Little Hatchet Mountains
- 19 Las Guijas Mountains
- 20 Swisshelm Mountains
- 21 Big Hatchet Mountains
- 22 Pozo Verde Mountains
- 23 Canelo Hills
- 24 Pedregosa Mountains
- 25 Animas Mountains
- 26 Atascosa Mountains
- 27 Patagonia Mountains
- 28 Huachuca Mountains
- 29 Mule Mountains
- 30 San Luis Mountains
- 31 Alamo Hueco Mountains
- 32 Sierra El Humo
- 33 Pajarito Mountains
- 34 Sierra San Antonio
- 35 Sierra San Jose
- 36 Sierra La Ceniza
- 37 Sierra de Embudos
- 38 Sierra San Luis
- 39 Sierra San Juan
- 40 Sierra Avispas
- 41 Sierra El Chivato
- 42 Sierra Las Minitas
- 43 Sierra Cibuta
- 44 Sierra El Pinito
- 45 Sierra La Mariquita
- 46 Sierra Elenita
- 47 Sierra de Los Ajos
- 48 Sierra Las Espuelas
- 49 Sierra La Cabellera
- 50 Sierra Azul
- 51 Sierra El Manzanal
- 52 Sierra La Madera
- 53 Cerro Bacoachi
- 54 Sierra Buenos Aires
- 55 Sierra El Pinito
- 56 Sierra San Antonio
- 57 Sierra Purica
- 58 Sierra El Jacaral
- 59 Cerro El Bellotal
- 60 Sierra La Sandia
- 61 Sierra Aconchi
- 62 Sierra de Oposura
- 63 Sierra Las Guijas
- 64 Sierra Los Azules
- 65 Sierra Mazatán



SKY ISLAND ARCHIPELAGO

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Figure 1—Elevation map of the Sky Island Region with 65 Sky Island mountains labeled. Green shading indicates approximate area above 1600 m (5250 ft), roughly the elevation at which oak woodlands first begin, although there is considerable variation in this due to latitude, slope and aspect, rainfall patterns, etc. (Map based on cartographic GIS research by Joel Viers/Lirica.)

peninsula” of the Sierra Madre Occidental. This said, it is known that these woodland connections have been greatly diminished by drought, fires, and tree cutting and in the near future this “peninsula” may become an “island” as it is surrounded on the other three sides by the Río Bavispe. Nevertheless, for historical biogeographic purposes, the El Tigre mountain complex is part of the Sierra Madre. South of the huge Sierra el Tigre complex in Sonora, thornscrub surrounds most of the ranges south to the Sierra de Mazatán.

The “Apachian Floristic District” (of McLaughlin 1995) and the “Apachian Subprovince” (of the larger Madrean Floristic Province) largely coincide with our definitions of the Madrean Sky Island Region. The 12.146-million ha “Apache Highlands Ecoregion” (of The Nature Conservancy) somewhat exceeds our view of the Sky Island Region in that it extends northwest through the Verde River and Big Chino Valleys of central Arizona to the Mogollon Rim, and south to include the northernmost region of the Sierra Madre Occidental.

Mountain Islands vs. Habitat Islands—A mountain range in this region is traditionally defined as a “Sky Island” if it is high enough to include Oak Woodland habitat and is not connected by Oak Woodlands to the Cordilleran ranges of the Rocky Mountains/Colorado Plateau or the Sierra Madre Occidental (Heald 1951; Dimmitt and others 2011). Using this definition, we recognize ~65 mountain ranges that should be designated as Sky Islands, 32 of which are in the United States (table 1).

Table 1—Alphabetical list of the 32 Madrean Sky Islands in the United States, with elevations of highest peaks.

Mountain Range (State)	Elevation (ft)	Elevation (m)
Alamo Hueco Mountains (NM)	6159	1877
Animas Mountains (NM)	8642	2634
Atascosa Mountains (AZ)	6422	1957
Baboquivari Mountains (AZ)	7734	2357
Big Hatchet Mountains (NM)	8366	2550
Canelo Hills (AZ)	5861	1786
Chiricahua Mountains (AZ)	9763	2976
Dos Cabezas Mountains (AZ)	8354	2546
Dragoon Mountains (AZ)	7523	2293
Galiuro Mountains (AZ)	7663	2336
Huachuca Mountains (AZ)	9466	2885
Las Guijas Mountains (AZ)	4665	1422
Little Dragoon Mountains (AZ)	6732	2052
Little Hatchet Mountains (NM)	6247	1904
Mule Mountains (AZ)	7360	2243
Pajarito Mountains (AZ)	5460	1664
Patagonia Mountains (AZ)	7221	2201
Pedregosa Mountains (AZ)	6540	1993
Peloncillo Mountains (AZ, NM)	6931	2113
Pinal Mountains (AZ)	7848	2392
Pinaleño Mountains (AZ)	10724	3269
Pozo Verde Mountains (AZ)	4701	1433
Rincon Mountains (AZ)	8664	2641
San Luis Mountains (NM, CHI)	8268	2520
Santa Catalina Mountains (AZ)	9157	2791
Santa Rita Mountains (AZ)	9456	2882
Santa Teresa Mountains (AZ)	8282	2524
Sierrita Mountains (AZ)	6190	1887
Superstition Mountains (AZ)	6266	1900
Swisshelm Mountains (AZ)	7185	2190
Whetstone Mountains (AZ)	7711	2350
Winchester Mountains (AZ)	6921	2110

Table 2—The twenty-one Oak Woodland “habitat islands” (or Madrean Sky Island complexes) in the United States.

Mountain ranges connected by contiguous Oak Woodland habitat	
1.	Superstition and Pinal Mountains
2.	Santa Teresa Mountains
3.	Pinaleño Mountains
4.	Santa Catalina Mountains
5.	Rincon Mountains
6.	Sierrita Mountains
7.	Baboquivari and Pozo Verde Mountains
8.	Santa Rita Mountains
9.	Galiuro and Winchester Mountains
10.	Dos Cabezas, Chiricahua, Pedregosa, and Swisshelm Mountains
11.	Little Dragoon Mountains
12.	Dragoon Mountains
13.	Mule Mountains
14.	Whetstone Mountains
15.	Peloncillo Mountains (AZ and NM)
16.	Atascosa, Pajarito, Las Guijas Mountains (and Sierras Las Avispas and Cíbuta in Sonora)
17.	Huachuca and Patagonia Mountains and Canelo Hills (and Sierra San Antonio in Sonora)
18.	Animas Mountains (NM)
19.	Big Hatchet and Little Hatchet Mountains (NM)
20.	Alamo Hueco Mountains (NM)
21.	San Luis Mountains (NM) (and Sierras San Luis, Las Espuelas, La Caballena, Embudos, and Minitas, in Sonora and Chihuahua)

In reality, 18 of the 32 named mountain ranges north of the border are connected to at least one other range by contiguous Oak Woodland and thus these 32 ranges can be classified into 21 distinct Sky Island complexes (table 2). Many of the Sonoran Sky Islands are connected to one another by Oak Woodland also, and, in the future, with improved information these could be combined into mountain complexes as we’ve done in table 2. The 21 U.S. mountain complexes that are connected by Oak Woodland can be thought of, ecologically and biogeographically as 21 “Oak Woodland islands” or “habitat islands.” Many of these mountain ranges are high enough to also harbor higher elevation biomes (e.g., Pine-Oak Woodlands, Chaparral, Pine Forest). However, to date, we have not determined how many contiguous vs. isolated landscapes of these higher elevation biomes exist. These concepts have considerable relevance for the biogeography of arthropods that inhabit these montane biomes.

In addition, some Sky Island mountain ranges actually comprise two or more subranges, even though maps and common usage typically use the name of only the largest of these. For example, the Baboquivari Mountains actually comprise four ranges—the Coyote, Quinlan, Pozo Verde, and Baboquivari Mountains—separated from one another by distinct valleys. But, popular usage refers to them collectively as the Baboquivari Mountains. This situation is especially troublesome in Mexico where we have tried to determine the most commonly used name for such ranges. Many Mexican ranges also have more than one name due to local usage, etc., and we have relied on the INEGI (Instituto Nacional de Estadística y Geografía) 1:250,000 maps of Sonora and Chihuahua for these names. We used USGS and INEGI information, and a Garmin 62S GPS device, for estimating elevation data.

Biomes of Arizona's Sky Islands

Ecologists generally agree that there are about a dozen major plant community types that occur worldwide, e.g., tundra/alpine, temperate broadleaf forests, Mediterranean woodlands/shrublands, tropical rain forests, coniferous forests, temperate and tropical Grasslands, temperate and tropical savannahs, tropical dry forests, Chaparral, savannahs, and deserts. Examples of all but the first four are found in the Madrean Sky Island Region. We refer to these as “biomes” in this study.

Here, we follow the Whittaker and Niering (1968b), Whittaker and others (1968), and Niering and Lowe (1985) studies of the vegetation of the Santa Catalina Mountains in recognizing the following biomes for the Sky Islands of Arizona: Desertscrub, Desert Grassland, grazing disturbed Grassland, Oak-Grassland, Oak Woodland, Pine-Oak Woodland, Chaparral, Pine Forest, and Mixed Conifer Forest. Whittaker and Niering (1965, 1968) listed the signature species for each of these biomes in their now classic diagrams depicting the biomes of the Santa Catalina Mountains. Not all of the Madrean Sky Islands are high enough to have all of these biomes, and many lack Pine Forest and/or Mixed Conifer Forest, especially in Mexico. However, all eight of these biomes occur in the Santa Catalina Mountains.

The elevational ordering of these biomes, and the strong Madrean component of most of the Sky Islands, were first formally described by Forrest Shreve early in the twentieth century (Shreve 1915, 1919, 1922, 1936, 1951). Joseph Marshall's 1957 study of the birds of Pine-Oak Woodlands of the border region also described the stacking of biotic communities on each island mountain from the Mogollon Rim to the Sierra Madre, and it was Marshall who defined the “Madrean Archipelago” as those mountains with Mexican Pine-Oak Woodlands in the Cordilleran Gap. In 1951, Weldon Heald, studying and living in the Chiricahua Mountains, coined the evocative and descriptive phrase “Sky Islands” for these ranges. Also in the 1960s, the pioneering ecological studies of Robert Whittaker, William Niering, and Charles Lowe described the botany of these ranges in growing detail. Comprehensive descriptions of Arizona's Sky Island biomes can also be found in the forthcoming book *A Natural History of the Santa Catalina Mountains, Arizona, with an Introduction to the Madrean Sky Islands* (Moore and Brusca, in press, Arizona-Sonora Desert Museum Press).

ASAP Surveys in the Santa Catalina Mountains

Catalinas Elevational Gradients

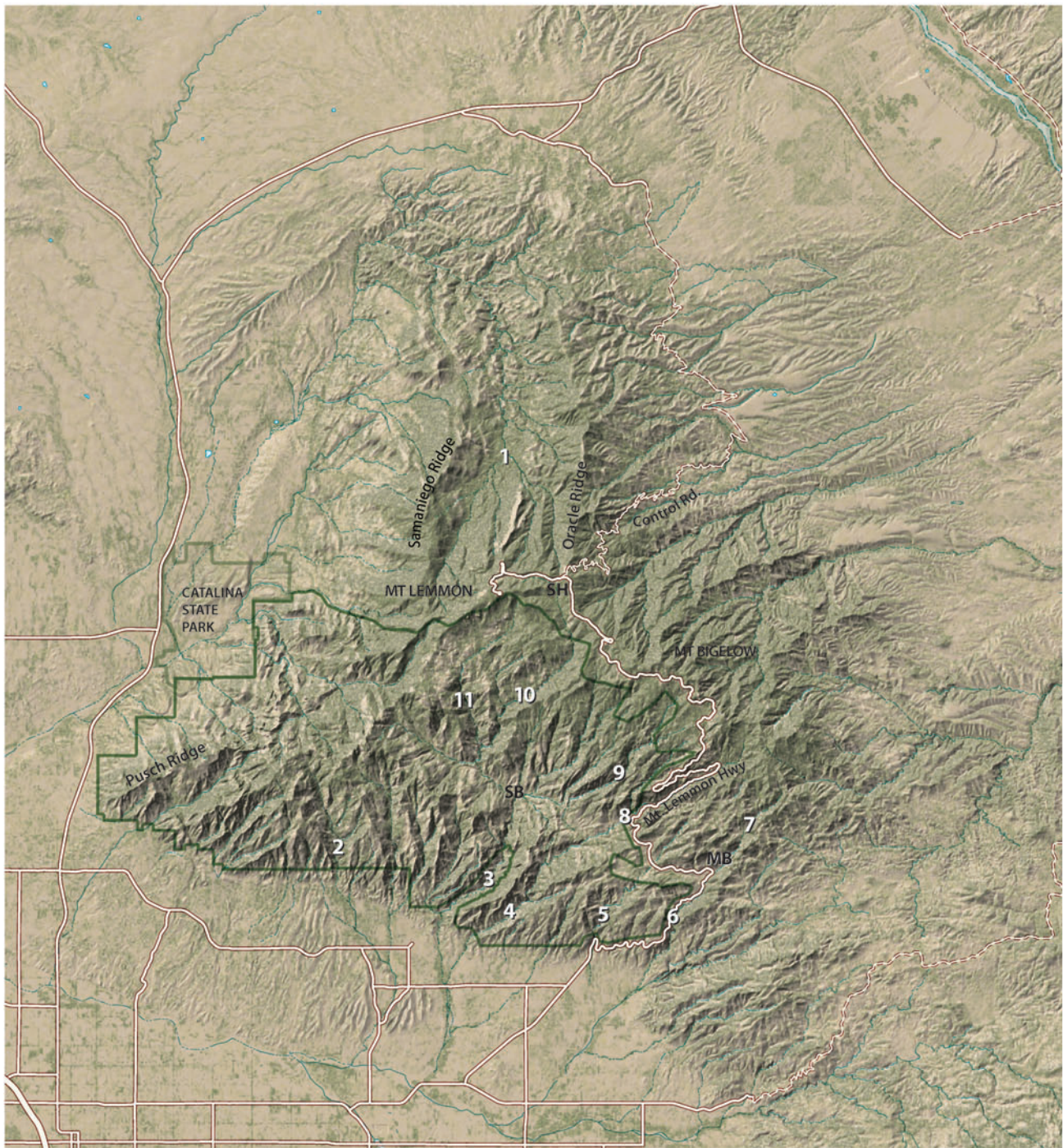
Situated 140 km north of the United States-Mexico border, the Santa Catalina Mountains are one of the best-known Sky Islands. To assess the diversity and distribution of ground-dwelling arthropods along elevation and environmental gradients, 66 sampling sites were identified in recognizable biomes along the elevation gradients of the southern and northern sides of the Santa Catalina Mountains, along the Mt. Lemmon Highway (south side), the Control Road (north side), and on Mt. Lemmon and Mt. Bigelow (fig. 2). These same elevation gradients along the same roads were studied botanically by Lowe (1961), Whittaker and Niering (1964, 1965, 1968a,b, 1975), Niering and Lowe (1985), and Whittaker and others (1968). Whittaker and others (1968) established 30 0.1-ha quadrats (20 x 50 m) for their plant censuses. Our study used 66 belt transects, each 0.02 ha in size (2 x 100 m) for species-X-abundance plant censuses. Neither the study by Whittaker and others (1968) nor our initial study examined riparian

or “wet canyon” sites; i.e., all transect sites established during the first year of the project are upland sites. In total we established 28 sites each on the southern and northern slopes of the Catalina Mountains and 10 mixed conifer sites on Mt. Lemmon and Mt. Bigelow.

While past workers have been in agreement about the over-arching sense of plant species turnover and plant community change with elevation, they have agreed only partly in where to draw lines separating these biomes, and what to call them. Forrest Shreve, in his benchmark 1915 paper, separated the slopes of the Catalina Mountains into three broad zones based on the biogeographic roots of the predominant plants: Desertscrub, “encinal” (dominated by Madrean species), and “forest” (dominated by Rocky Mountain/Petran species). Shreve's idea was compelling, but it does not work well for all the other Sky Islands, especially those on the fringes of the Sky Island region whose plant community affinities are not so clear-cut. It also largely ignored the grasses and the importance of Grassland habitat on the Sky Islands. In a detailed series of papers by Whittaker, Niering, and Lowe, Shreve's ideas were refined into something very close to what we use in this paper. Our scheme is a slight alteration of the scheme presented in Niering and Lowe's 1985 publication, and it is based on vegetation analyses of 66 transect sites in the Catalina Mountains established by the ASAP Project (table 3, fig. 2).

In each biome, 100-m long transects were placed farther than 0.25 km from the road, to minimize possible road effects. On the south side of the range we established five transects in Desertscrub (at elevations of 1045–1172 m), six in Oak-Grassland (at elevations of 1384–1433 m), seven in Pine-Oak Woodland (at elevations of 1803–2422 m), two in Chaparral (at elevations of 1923–2052 m), and eight in Pine Forest (at elevations of 2224–2463 m). On the north side of the range we established seven transects in disturbed Desert Grassland (historically grazed areas at elevations of 1323–1451 m), six in relatively undisturbed Desert Grassland (at elevations of 1330–1645 m), two in Oak Woodland (at elevations of 1939–2000 m), five in Pine-Oak Woodland (2032–2149 m), five in Chaparral (at elevations of 1845–1971 m), and four in Pine Forest (at elevations of 2218–2305 m). Ten transects in mixed conifer habitat were established in the Mt. Lemmon and Mt. Bigelow areas (at elevations of 2442–2777 m).

The southern slope elevation gradient along the Mt. Lemmon Highway does not have good Oak Woodland or Grassland; all grass habitats on the south side were deemed to be Oak-Grassland, a fact also observed by Whittaker and Niering (1965), although good Desert Grassland can be found by hiking west from Molino Basin a few miles on the Arizona Trail. The northern slope elevation gradient along the Control Road has no Desertscrub, it begins near the town of Oracle at 1220 m in elevation, a fact observed by Forrest Shreve and all subsequent works since the 1920s. However, the northern slope does have highly disturbed, overgrazed Grassland that has converted to scrubland (which we sampled) that resembles Desertscrub as overgrazed Grassland does throughout southern Arizona. The reduction of grasses by livestock and fire suppression, and the subsequent invasion by woody and shrubby desert plants in the Southwest, has been known since Aldo Leopold (1924) and a large literature exists on this subject. The north side also had no Oak-Grassland; it did, however, have relatively undisturbed Desert Grassland and some patches of Oak Woodland. Of course, it has long been recognized that these biomes, or plant communities, intergrade continuously (Whittaker and others 1968; Brown and Lowe 1980), and local variations in vegetation are due to gradients of slope, soil type, slope aspect, etc. This was a major focus of Whittaker and his colleagues' work in the Sky Islands for many years. A detailed series of papers (Whittaker and Niering 1964, 1965, 1968a,b, 1975; Whittaker and others 1968) explored relationships between plant species and a variety of



SANTA CATALINA MOUNTAINS

CANYON KEY

- | | | |
|------------------------|------------------------|-------------------------|
| 1. Cañada del Oro | 5. Soldier Canyon | 9. Sycamore Canyon |
| 2. Ventana Canyon | 6. Lower Molino Canyon | 10. Upper Sabino Canyon |
| 3. Lower Sabino Canyon | 7. Upper Molino Canyon | 11. Lemmon Canyon |
| 4. Lower Bear Canyon | 8. Upper Bear Canyon | |

LETTER KEY

- | | |
|----|--------------|
| MB | Molino Basin |
| SB | Sabino Basin |
| SH | Summerhaven |

 Pusch Ridge Wilderness

Figure 2—The Santa Catalina Mountains from space showing location of major topographic features as well as the Mt. Lemmon Highway and the Control Road.

Table 3—Summary of the 66 Catalina transects.

Biome type ^a	Elevation and Aspect ^b	Transect Coordinates ^c	Comments [transect field code identifier]
Desertscrub (S)	1045m/3428ft S (170°)	32.30978 N, 110.73497 W	Classic Arizona Upland (Soldier Canyon Trail) [CAT-DS-S-01]
Desertscrub (S)	1133m/3717ft S (180°)	32.31060 N, 110.71922 W	Arizona Upland with some grassland species (Babad Do'ag Trail). Large patches of Lehmann lovegrass in area. [CAT-DS-S-03]
Desertscrub (S)	1159m/3802ft SE (144°)	32.31163 N, 110.71733 W	Arizona Upland with some grassland species (Babad Do'ag Trail). Large patches of Lehmann lovegrass in area. [CAT-DS-S-04]
Desertscrub (S)	1172m/3845ft NE to S (65° to 170°)	32.31366 N, 110.71221 W	Arizona Upland with some grassland species (east of Babad Do'ag Trail). Transect slope faces toward Molino Canyon. [CAT-DS-S-05]
Desertscrub (S)	1160m/3806ft S (175°)	32.31263 N, 110.71693 W	Arizona Upland with some grassland species (Babad Do'ag Trail). Large patches of Lehmann lovegrass in area. [CAT-DS-S-06]
Oak-Grassland (S)	1384m/4541ft NNW (340°)	32.33543 N, 110.7044 W	Along Arizona Trail, near Molino Basin Campground area. Some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-GL-S-01]
Oak-Grassland (S)	1400m/4593ft E (90°)	32.33604 N, 110.70673 W	Along Arizona Trail, near Molino Basin Campground area. Some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-GL-S-02]
Oak-Grassland (S)	1492m/4895ft	32.33690 N, 110.7180 W	Near Gordon Hirabayashi Picnic area. [CAT-GL-S-03]
Oak-Grassland (S)	1477m/4845ft SW (245°)	32.33751 N, 110.72071 W	Near Gordon Hirabayashi Picnic area. Some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-GL-S-04]
Oak-Grassland (S)	1513m/4964ft NE (25°)	32.34452 N, 110.71972 W	Near Bug Spring Trailhead. Quite a few chaparral plants at this site; some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-GL-S-05]
Oak-Grassland (S)	1533m/5030ft NW (315°)	32.34448 N, 110.71769 W	Near Bug Spring Trailhead. Quite a few chaparral plants at this site; some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-GL-S-06]
Pine-Oak Woodland (S)	1803m/5915ft N (360°)	32.37395 N, 110.69254 W	Near Middle Bear Canyon Picnic Area. [CAT-PO-S-01]
Pine-Oak Woodland (S)	2122m/6962ft	32.38335 N, 110.69482 W	[CAT-PO-S-02]
Pine-Oak Woodland (S)	2183m/7162ft	32.39205 N, 110.69728 W	Below Rose Canyon Rd. parking area. [CAT-PO-S-03]
Pine-Oak Woodland (S)	2266m/7434ft SW (205°)	32.40078 N, 110.70033 W	[CAT-PO-S-04]
Pine-Oak Woodland (S)	2422m/7946ft SE (150°)	32.40951 N, 110.71229 W	Below Visitor's Center. This high Pine-Oak site is transitional to Pine Forest. [CAT-PO-S-05]
Pine-Oak Woodland (S)	2209m/7247ft SW (215°)	32.4004 N, 110.6909 W	Near San Pedro Vista area. [CAT-PO-S-06]
Pine-Oak Woodland (S)	2030m/6660ft NNW (345°)	32.37546 N, 110.70695 W	Near Hoo Doo Vista area. [CAT-PO-S-07]
Chaparral (S)	2052m/6732ft SSE (163°)	32.36873 N, 110.71519 W	Above Windy Point Vista. Some oaks in this area burned in 2003 Aspen Fire (regrowing from root crowns). [CAT-CH-S-01]
Chaparral (S)	1923m/6309ft S (180°)	32.37292 N, 110.70142 W	Near Manzanita Vista area. [CAT-CH-S-02]
Pine Forest (S)	2224m/7297ft WNW (285°)	32.39534 N, 110.69073 W	Near Rose Canyon Rd. parking area. [CAT-P-S-01]
Pine Forest (S)	2386m/7829ft NE (30°)	32.42924 N, 110.74430 W	Near Sunset Trail parking area. [CAT-P-S-03]

(continued)

Table 3 Continued

Biome type ^a	Elevation and Aspect ^b	Transect Coordinates ^c	Comments [transect field code identifier]
Pine Forest (S)	2324m/7625ft E (100°)	32.42886 N, 110.75649 W	Marshall Gulch Picnic Area. [CAT-P-S-04]
Pine Forest (S)	2296m/7534ft NE (50°)	32.42772 N, 110.75578 W	Marshall Gulch Picnic Area. [CAT-P-S-05]
Pine Forest (S)	2447m/8028ft WNW (300°)	32.42004 N, 110.73919 W	Near Box Camp parking area. [CAT-P-S-06]
Pine Forest (S)	2401m/7877ft WSW (250°)	32.42699 N, 110.73949 W	Near Butterfly Trailhead. [CAT-P-S-07]
Pine Forest (S)	2394m/7854ft SSW (200°)	32.43175 N, 110.75110 W	Near Sykes Knob-Inspiration Point. [CAT-P-C-02]
Pine Forest (S)	2463m/8081ft SSW (200°)	32.41498 N, 110.73312 W	1 mi. below Box Camp parking area. [CAT-P-C-03]
Mixed Conifer Forest (MTN)	2442m/8012ft WSW (200°)	32.42227 N, 110.73134 W	Bear Wallow area. [CAT-MC-S-01]
Mixed Conifer Forest (MTN)	2452m/8045ft E (90°)	32.41866 N, 110.73264 W	Bear Wallow area. [CAT-MC-S-02]
Mixed Conifer Forest (MTN)	2514m/8248ft W (270°)	32.41514 N, 110.72688 W	Near observatory on Mt. Bigelow. [CAT-MC-S-03]
Mixed Conifer Forest (MTN)	2551m/8369ft NE (38°)	32.41360 N, 110.72114 W	Near large Aspen grove, Mt. Bigelow. [CAT-MC-S-04]
Mixed Conifer Forest (MTN)	2530m/8301ft NE (50°)	32.41807 N, 110.72465 W	Near observatory on Mt. Bigelow. [CAT-MC-S-05]
Mixed Conifer Forest (MTN)	2777m/9111 ft N (360°)	32.44134 N, 110.78623 W	Sky Center parking lot area, Mt. Lemmon. [CAT-MC-02]
Mixed Conifer Forest (MTN)	2691m/8829ft N (355°)	32.44480 N, 110.78666 W	Near top of ski run area ("Heidi's Meadow"), Mt. Lemmon. [CAT-MC-03]
Mixed Conifer Forest (MTN)	2587m/8488ft WNW (285°)	32.45196 N, 110.78396 W	Ski slope area, Mt. Lemmon. [CAT-MC-04]
Mixed Conifer Forest (MTN)	2541m/8337ft NE (35°)	32.44643 N, 110.77675 W	Along Aspen Draw Trail, Mt. Lemmon. [CAT-MC-05]
Mixed Conifer Forest (MTN)	2564m/8412ft NE (35°)	32.44588 N, 110.77711 W	Along Aspen Draw Trail, Mt. Lemmon. [CAT-MC-06]
Grazing-Disturbed Grassland (N)	1363m/4472ft NE (65°)	32.5805 N, 110.7214 W	At Arizona Trail crossing of Control Rd., near old ranch house. [CAT-DS-N-03]
Grazing-Disturbed Grassland (N)	1401m/4597ft W (265°)	32.57300 N, 110.70277 W	At Arizona Trail crossing of Control Rd., next to old ranch house. [CAT-DS-N-04]
Grazing-Disturbed Grassland (N)	1337m/4386ft SE (130°)	32.5692 N, 110.7119 W	Near Sombrero Viejo Rd. (5 mi. from start of Control Rd. at Oracle). [CAT-DS-N-05]
Grazing-Disturbed Grassland (N)	1341m/4340ft SW (220°)	32.56757 N, 110.71040 W	Near Sombrero Viejo Rd. (5 mi. from start of Control Rd. at Oracle). [CAT-DS-N-06]
Grazing-Disturbed Grassland (N)	1451m/4760ft NNW (340°)	32.54188 N, 110.7139 W	Near Peppersauce Canyon Trail crossing (8 mi. from start of Control Rd. at Oracle). Limestone outcrop with many ocotillo. [CAT-DS-N-07]
Grazing-Disturbed Grassland (N)	1440m/4624ft NW (315°)	32.54196 N, 110.71013 W	Near Peppersauce Canyon Trail crossing, but not on limestone outcropping. [CAT-DS-N-08]
Grazing-Disturbed Grassland (N)	1380m/4528ft NNW (345°)	32.51539 N, 110.68622 W	[CAT-GL-N-06]
Desert Grassland (N)	1488m/4882ft SE (135°)	32.53323 N, 110.71042 W	90% grass ground cover; some livestock disturbance evident. [CAT-GL-N-01]
Desert Grassland (N)	1330m/4364ft NNE (20°)	32.49794 N, 110.68372 W	40% grass ground cover; on limestone outcrop. [CAT-GL-N-02]
Desert Grassland (N)	1492m/4895ft SE (145°)	32.48673 N, 110.70566 W	90% grass ground cover, but mostly Lehmann's lovegrass. [CAT-GL-N-03]
Desert Grassland (N)	1504m/4934ft NE (40°)	32.47964 N, 110.71066 W	70% ground cover, almost entirely grass. [CAT-GL-N-04]
Desert Grassland (N)	1645m/5397ft	32.47811 N, 110.72174 W	[CAT-GL-N-05]

(continued)

Table 3 Continued

Biome type ^a	Elevation and Aspect ^b	Transect Coordinates ^c	Comments [transect field code identifier]
Chaparral (N)	1845m/6053ft W (260°)	32.46355 N, 110.73198 W	50% ground cover, mostly grasses. [CAT-CH-N-01]
Chaparral (N)	1865m/6119ft SE (120°)	32.46395 N, 110.73276 W	65% ground cover, mostly grasses. [CAT-CH-N-02]
Chaparral (N)	1925m/6316ft NE (35°)	32.46138 N, 110.73971 W	[CAT-CH-N-05]
Chaparral (N)	1962m/6437ft E (90°)	32.45885 N, 110.74123 W	[CAT-CH-N-06]
Chaparral (N)	1971m/6467ft NE (50°)	32.45707 N, 110.73774 W	[CAT-CH-N-07]
Oak Woodland (N)	1939m/6362ft SE (150°)	32.46448 N, 110.74242 W	[CAT-OW-N-01]
Oak Woodland (N)	2000m/6562ft ESE (109°)	32.45633 N, 110.73994 W	55% ground cover, much of it bullgrass (<i>Muhlenbergia emersleyi</i>). [CAT-OW-N-02]
Pine-Oak Woodland (N)	2032m/6667ft NE (40°)	32.45313 N, 110.73906 W	30-40% ground cover, much of it bullgrass (<i>Muhlenbergia emersleyi</i>). [CAT-PO-N-01]
Pine-Oak Woodland (N)	2080m/6824ft S (170°)	32.44946 N, 110.73728 W	[CAT-PO-N-02]
Pine-Oak Woodland (N)	2142m/7028ft N (360°)	32.45270 N, 110.74248 W	Thick Fendler buckbrush; evidence of pine beetles. [CAT-PO-N-03]
Pine-Oak Woodland (N)	2149m/7051ft NE (65°)	32.45264 N, 110.74379 W	Thick Fendler buckbrush. [CAT-PO-N-04]
Pine-Oak Woodland (N)	2313m/7589ft SSE (165°)	32.45171 N, 110.75072 W	This is a Pine-Oak/Pine Forest transitional site. ~50% live plant ground cover. [CAT-P-N-05]
Pine Forest (N)	2218m/7277ft S (175°)	32.44029 N, 110.74741 W	~5% live plant ground cover. [CAT-P-N-01]
Pine Forest (N)	2228m/7310ft E (80°)	32.45215 N, 110.74773 W	~5% live plant ground cover. [CAT-P-N-02]
Pine Forest (N)	2280m/7480ft SE (130°)	32.45063 N, 110.75037 W	~5% live plant ground cover. [CAT-P-N-03]
Pine Forest (N)	2305m/7562ft NE (45°)	32.44910 N, 110.75069 W	~5% live plant ground cover. [CAT-P-N-04]

^a N = Northern slope transects (along Control Road); S = Southern slope transects (along Mt. Lemmon Highway); MTN = High elevation transects, on Mt. Lemmon and Mt. Bigelow.

^b Aspect is that of prevailing slope of transect (with compass heading).

^c Starting location of transect

environmental factors. It is not our goal to repeat those analyses but rather to accurately describe and classify the botany of our arthropod transect sites.

Transect sites for our 2011 fieldwork in the Catalina Mountains were categorized according to six environmental variables: elevation, slope, aspect, biome, as well as ground temperature and humidity. A Log-Tag HAXO-8 temperature and humidity recorder was placed 2 cm above the soil/litter in the center of each of the 66 transects. Log-Tags were placed in the field on May 6, 2011 and they recorded data every 30 min. Average temperature data for each site along the elevation gradients from May 7, 2011, through September 14, 2011, is plotted according to elevation and biome (fig. 3). Although we did not statistically analyze the temperature data, it is apparent that north- and south-side temperatures (per elevation) were not markedly different, and this is probably partly due to the fact that this was the hottest time of the year, although differences in slope aspect and other factors probably also contributed to evening out these averages. Nonetheless, the overall negative correlation between temperature vs. elevation and biome is clear.

Ground Dwelling Arthropod Surveys

We set 10 pitfall traps arranged 10 m apart along each 100-m transect line. Pitfall trap design was adopted from Higgins (2010). Each trap consists of a heavy Pyrex glass “test tube” (3.2 cm diameter, 25 cm deep) inserted in a PVC sleeve (3.8 cm in diameter, 28 cm long) that had been buried in the ground. The opening of the trap is flush with the soil surface, and the glass sampling tubes can be exchanged while leaving the PVC sleeve in place. Traps were charged with propylene glycol (50% full). A PVC rain shield covers the opening of the trap, 3–4 cm above the ground. When the glass tubes are not in place, the PVC sleeves are capped to prevent them from filling with dirt or inadvertently capturing any animals.

In 2011 we sampled for 2 weeks in the spring (pre-monsoon, May 1–15) and 2 weeks in the late summer (post-monsoon, September 1–15). This project represents the first effort to extensively and quantitatively sample the arthropod fauna of any of the Sky Islands of the Madrean Archipelago and, as such, will provide baseline data on the abundance, diversity, and community structure of this exceptionally diverse group for future studies.

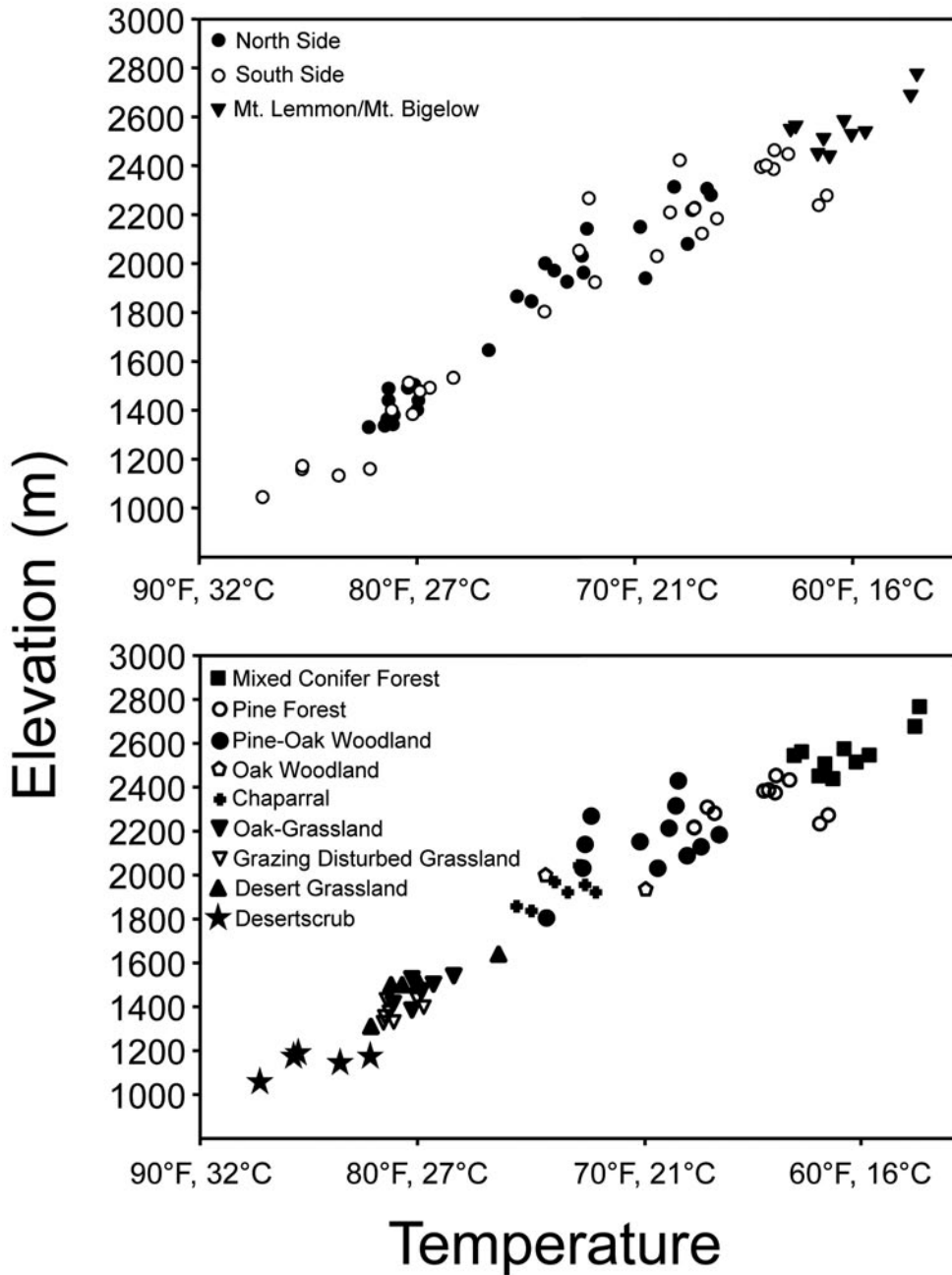


Figure 3—Average summer temperatures collected 7-May-2011 to 14-Sept-2011 along the transect elevation gradients in the Santa Catalina Mountains. Top: A comparison of average temperatures at sites on the South and North sides of the mountain, as well as those found at the highest elevations on Mt. Lemmon and Mt. Bigelow. Bottom: A comparison of average temperatures at sites in different plant biomes.

Here, we present preliminary species lists of the ants and carabid beetles based on our first round of pitfall-trap sampling. These data were supplemented from specimen-level data in the University of Arizona Insect Collection to develop working lists of the known species from the Santa Catalina Mountains. We expect these species lists to grow with future collecting and monitoring efforts.

Ants—The ants, family Formicidae, are possibly the numerically dominant family of insects. Ants represent 10–15% of the entire animal biomass in terrestrial ecosystems (Hölldobler and Wilson 1990). Ants

have played a significant role in the evolution of modern terrestrial biotic communities for at least the last 40–50 million years. More species of ants occur in Arizona than in any other U.S. State (Johnson 1996). While there have been no extensive surveys of the ant fauna of the Santa Catalina Mountains, we expect their diversity to be similar to that of other Sky Islands of comparable area and elevation range. The most well-known Sky Island ant fauna is that of the Chiricahua Mountains where 187 species have been documented, representing 59% of the total known ant fauna of Arizona (Stephan Cover, personal

Table 4—Ant species known from the Santa Catalina Mountains.

<p>Dolichoderinae</p> <p><i>Dorymyrmex bicolor</i> Wheeler, 1906</p> <p><i>Forelius mccooki</i> (McCook, 1880)</p> <p><i>Forelius pruinosus</i> (Roger, 1863)</p> <p><i>Liometopum apiculatum</i> Mayr, 1870</p> <p><i>Liometopum luctuosum</i> Wheeler, 1905</p> <p><i>Tapinoma sessile</i> (Say, 1836)</p> <p>Ecitoninae</p> <p><i>Neivamyrmex andrei</i> (Emery, 1901)</p> <p><i>Neivamyrmex harrisii</i> (Haldeman, 1852)</p> <p><i>Neivamyrmex nigrescens</i> (Cresson, 1872)</p> <p><i>Neivamyrmex opacithorax</i> (Emery, 1894)</p> <p><i>Neivamyrmex texanus</i> Watkins, 1972</p> <p>Formicinae</p> <p><i>Brachymyrmex depilis</i> Emery, 1893</p> <p><i>Camponotus festinatus</i> (Buckley, 1866)</p> <p><i>Camponotus fragilis</i> Pergande, 1893</p> <p><i>Camponotus laevigatus</i> (F. Smith, 1858)</p> <p><i>Camponotus modoc</i> Wheeler, 1910</p> <p><i>Camponotus pudorosus</i> Emery, 1925</p> <p><i>Camponotus sansabeanus</i> (Buckley, 1866)</p> <p><i>Camponotus schaefferi</i> Wheeler, 1909</p> <p><i>Camponotus vicinus</i> Mayr, 1870</p> <p><i>Formica aserva</i> Forel, 1901</p> <p><i>Formica densiventris</i> Viereck, 1903</p> <p><i>Formica fusca</i> Linnaeus, 1758</p> <p><i>Formica gnava</i> Buckley, 1866</p> <p><i>Formica neogagates</i> Viereck, 1903</p> <p><i>Formica moki</i> Wheeler, 1906</p> <p><i>Formica occulta</i> Francoeur, 1973</p> <p><i>Formica wheeleri</i> Creighton, 1935</p> <p><i>Lasius alienus</i> (Foerster, 1850)</p> <p><i>Lasius coleii</i> (Wing, 1968)</p> <p><i>Lasius flavus</i> (Fabricius, 1781)</p> <p><i>Lasius occidentalis</i> (Wheeler, 1909)</p> <p><i>Lasius pallitarsus</i> (Provancher, 1881)</p> <p><i>Lasius sitiens</i> Wilson, 1955</p> <p><i>Lasius subumbratus</i> (Viereck, 1903)</p> <p><i>Myrmecocystus flaviceps</i> Wheeler, 1912</p> <p><i>Myrmecocystus mendax</i> Wheeler, 1908</p> <p><i>Myrmecocystus mexicanus</i> Wesmael, 1838</p> <p><i>Myrmecocystus mimicus</i> Wheeler, 1908</p> <p><i>Myrmecocystus navajo</i> Wheeler, 1908</p> <p><i>Polyergus breviceps</i> Emery, 1893</p> <p><i>Prenolepis imparis</i> (Say, 1836)</p>	<p>Myrmicinae</p> <p><i>Aphaenogaster albisetosa</i> Mayr, 1886</p> <p><i>Aphaenogaster huachucana</i> Creighton, 1934</p> <p><i>Aphaenogaster texana</i> Wheeler, 1915</p> <p><i>Cephalotes rohweri</i> Wheeler, 1916</p> <p><i>Crematogaster browni</i> Buren, 1968</p> <p><i>Crematogaster depilis</i> Wheeler, 1919</p> <p><i>Crematogaster emeryana</i> Creighton, 1950</p> <p><i>Crematogaster lineolata</i> (Say, 1836)</p> <p><i>Crematogaster opuntiae</i> Buren, 1968</p> <p><i>Crematogaster vermiculata</i> Emery, 1895</p> <p><i>Messor pergandei</i> (Mayr, 1886)</p> <p><i>Myrmica tahoensis</i> Weber, 1948</p> <p><i>Myrmica wheeleri</i> Weber, 1939</p> <p><i>Pheidole cerebrosi</i> Wheeler, 1915</p> <p><i>Pheidole ceres</i> Wheeler, 1904</p> <p><i>Pheidole desertorum</i> Wheeler, 1906</p> <p><i>Pheidole diversipilosa</i> Wheeler, 1908</p> <p><i>Pheidole hyatti</i> Emery, 1895</p> <p><i>Pheidole obtusospinosa</i> Pergande, 1896</p> <p><i>Pheidole rhea</i> Wheeler, 1908</p> <p><i>Pheidole sciophila</i> Wheeler, 1908</p> <p><i>Pheidole spadonia</i> Wheeler, 1915</p> <p><i>Pheidole titanis</i> Wheeler, 1903</p> <p><i>Pheidole xerophila</i> Wheeler, 1908</p> <p><i>Pogonomyrmex barbatus</i> (F. Smith, 1858)</p> <p><i>Pogonomyrmex californicus</i> (Buckley, 1867)</p> <p><i>Pogonomyrmex desertorum</i> Wheeler, 1902</p> <p><i>Pogonomyrmex imberbiculus</i> Wheeler, 1902</p> <p><i>Pogonomyrmex maricopa</i> Wheeler, 1914</p> <p><i>Pogonomyrmex occidentalis</i> (Cresson, 1865)</p> <p><i>Solenopsis aurea</i> Wheeler, 1906</p> <p><i>Solenopsis xyloni</i> McCook, 1879</p> <p><i>Stenamma californicum</i> Snelling, 1973</p> <p><i>Stenamma chiricahua</i> Snelling, 1973</p> <p><i>Stenamma snellingi</i> Bolton, 1957</p> <p><i>Temnothorax andrei</i> (Emery, 1895)</p> <p><i>Temnothorax neomexicanus</i> (Wheeler, 1903)</p> <p><i>Temnothorax nitens</i> (Emery, 1895)</p> <p><i>Temnothorax rugatulus</i> (Emery, 1895)</p> <p><i>Temnothorax whitfordi</i> (Mackay, 2000)</p> <p><i>Tetramorium hispidum</i> (Wheeler, 1915)</p> <p><i>Tetramorium spinosum</i> (Pergande, 1896)</p> <p><i>Trachymyrmex arizonensis</i> (Wheeler, 1907)</p> <p>Ponerinae</p> <p><i>Odontomachus clarus</i> Roger, 1861</p> <p>Pseudomyrmecinae</p> <p><i>Pseudomyrmex apache</i> Creighton, 1953</p> <p><i>Pseudomyrmex pallidus</i> (F. Smith, 1855)</p>
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communication). To date, in the Santa Catalinas, 88 species have been identified through our pitfall traps and the University of Arizona Insect Collection (table 4).

Ground Beetles—The ground beetles, family Carabidae, comprise one of the largest beetle families with at least 40,000 described species worldwide. Most ground beetles represent apex predators of most soil arthropod communities and, thus, play an important ecological role in almost every terrestrial habitat. Because of this, they have been important subjects in ecological and climate change studies such as

the long-term climate change study presently being conducted by the National Ecological Observatory Network (NEON). There are over 2500 described species of Carabidae known from North America. Based on the holdings of the UAIC, over 300 species occur in the Sky Island Region of Arizona. Transect samples and UAIC collection records document 69 species of Carabidae occurring in the Santa Catalina Mountains (table 5).

Initial analyses of patterns of species distribution of carabids and ants find patterns for the fauna of the Santa Catalina Mountains similar to

Table 5—Carabid beetle species known from the Santa Catalina Mountains.

Anthiinae: Helluonini <i>Helluomorphoides latitarsis</i> (Casey, 1913)	Lebiinae: Odacanthini <i>Lachnophorus elegantulus</i> Mannerheim, 1843
Brachininae: Brachinini <i>Brachinus costipennis</i> Motschulsky, 1859 <i>Brachinus elongatulus</i> Chaudoir, 1876 <i>Brachinus favicollis</i> Erwin, 1965 <i>Brachinus gebhardis</i> Erwin, 1965 <i>Brachinus hirsutus</i> Bates, 1884 <i>Brachinus lateralis</i> Dejean, 1831 <i>Brachinus mexicanus</i> Dejean, 1831	Licininae: Chlaeniini <i>Chlaenius cumatilis</i> LeConte, 1851 <i>Chlaenius leucoscelis monachus</i> LeConte, 1851 <i>Chlaenius obsoletus</i> LeConte, 1851 <i>Chlaenius ruficauda</i> Chaudoir, 1856
Carabinae: Carabini <i>Calosoma peregrinator</i> Guérin-Méneville, 1844 <i>Calosoma prominens</i> LeConte, 1853	Nebrinae: Notiophilini <i>Notiophilus semiopacus</i> Eschscholtz, 1833
Carabinae: Cychrini <i>Scaphinotus petersi catalinae</i> Van Dyke, 1924	Paussinae: Ozaenini <i>Goniotropis kuntzeni</i> Banninger, 1927
Cicindelinae: Cicindelini <i>Amblycheila baroni</i> Rivers, 1890 <i>Cicindela lemniscata</i> LeConte, 1854 <i>Cicindela ocellata</i> Klug, 1834 <i>Cicindela sedecimpunctata</i> Klug, 1834	Platyninae: Platynini <i>Colpodes longiceps</i> (Schaeffer, 1910) <i>Platynus brunneomarginatus</i> (Mannerheim, 1843) <i>Platynus cohni</i> Liebherr and Will, 1996 <i>Platynus ovatulus</i> (Bates, 1884) <i>Platynus lyratus</i> (Chaudoir, 1878) <i>Platynus megalops</i> (Bates, 1882) <i>Platynus rufiventris</i> (Van Dyke, 1926) <i>Rhadine anthicoides</i> Casey, 1913 <i>Sericoda bembidioides</i> Kirby, 1837 <i>Synuchus dubius</i> (LeConte, 1854)
Dryptinae: Galeritini <i>Galerita atripes</i> LeConte, 1858 <i>Galerita mexicana</i> Chaudoir, 1872	Platyninae: Sphodrini <i>Calathus gregarius</i> (Say, 1823) <i>Calathus peropacus</i> Casey, 1920
Harpalinae: Anisodactyliini <i>Anisodactylus anthracinus</i> (Dejean, 1829) <i>Notiobia mexicana</i> (Dejean, 1829)	Pterostichinae: Pterostichini <i>Pterostichus adstrictus</i> Eschscholtz, 1823
Harpalinae: Harpalini <i>Discoderus congruens</i> Casey, 1914 <i>Discoderus pinguis</i> Casey, 1884 <i>Harpalus fraternus</i> LeConte, 1852 <i>Harpalus laevipes</i> Zetterstedt, 1828 <i>Selenophorus otiosus</i> Casey, 1914	Pterostichinae: Zabryni <i>Amara californica</i> Dejean, 1828
Harpalinae: Stenolophini <i>Bradycellus rupestris</i> (Say, 1823)	Scaritinae: Clivinini <i>Clivina ferrea</i> LeConte, 1857 <i>Schizogenius falli</i> Whitehead, 1972 <i>Schizogenius pygmaeus</i> Van Dyke, 1925
Lebiinae: Cyclosomini <i>Tetragonoderus fasciatus</i> (Haldeman, 1843)	Scaritinae: Scaritini <i>Pasimachus californicus</i> Chaudoir, 1850 <i>Pasimachus viridans</i> LeConte, 1858
Lebiinae: Lebiini <i>Apristus tuckeri</i> Casey, 1920 <i>Cymindis arizonensis</i> Schaeffer, 1910 <i>Cymindis punctiger</i> LeConte, 1851 <i>Lebia abdita</i> Madge, 1967 <i>Lebia histrionica</i> Bates, 1883 <i>Lebia pimalis</i> (Casey, 1920) <i>Lebia pulchella</i> Dejean, 1826 <i>Lebia tuckeri</i> (Casey, 1920) <i>Lebia viridis</i> Say, 1823	Trechinae: Bembidiini <i>Bembidion flavopictum</i> Casey, 1918 <i>Bembidion mexicanum</i> Dejean, 1831 <i>Bembidion rapidum</i> (LeConte, 1848) <i>Bembidion striola</i> LeConte, 1852 <i>Bembidion subangustatum</i> Hayward, 1897 <i>Elaphropus nebulosus</i> (Chaudoir, 1868) <i>Pericompsus laetulus</i> LeConte, 1852 <i>Tachyta nana inornata</i> (Say, 1823)

those Halffter (1987) recognized in the mountains of Mexico. Species with temperate ancestral distributions are generally found at higher elevations (Pine Forest and Mixed Conifer Forest), while Neotropical species are generally found at lower elevations (Desertscrub, Desert Grassland, and Oak Woodland). This pattern is also similar to those reported in the studies of Ball (1968), Liebherr (1994), and Marshall and Liebherr (2000) for montane carabids in Mexico. For example,

in the Catalinas, the temperate genus *Scaphinotus* is represented by one species, *Scaphinotus petersi catalinae* Van Dyke, which is restricted to Pine Forest and Mixed Conifer Forest and the tropical genus *Goniotropis*, represented by *Goniotropis kuntzeni* Banninger, which is restricted to Oak-Grassland. The Madrean Archipelago and the neighboring northern Sierra Madre mountains are the only areas in the world where members of these two genera, with such disparate ancestral distributions, can be found within the same mountain range.

Plant Surveys

Plant surveys were conducted August 5-14, 2011. Surveys were made for each transect site in two ways. First, the transect line was walked and every plant recorded within one meter on either side of the line. This produced a 200-m² belt transect record of plant species and abundance. Then, the transect was walked again, this time scanning the broader area outside the 200-m² area, noting the presence but not abundances of any plants that might not have been in the belt transect itself. For practical reasons, Rocky Mountain ponderosa pine and Arizona pine were counted together, and no attempt was made to distinguish between these two species. In the Catalina Mountains, the Coronado National Forest manages these as a “single species,” and past workers have considered Arizona pine to be a variety of ponderosa (*P. ponderosa* var. *arizonica*), although this is not current opinion.

Surveys of plants in the 66 transect sites in the Catalina Mountains recorded a total of 316 species: 24 trees, 30 woody shrubs, 23 stem and rosette succulents (including one hybrid agave), 38 grasses, and 201 small shrubs, herbs and annuals. Data are summarized in table 6, and a complete list of plants-by-biome is given in table 7. For each biome, there are two species lists, one of “common species” that occurred in two or more transects and the other of “uncommon species” that occurred in only one transect. The complete plant database is available from W. Moore. Whittaker and Niering’s (1964) benchmark study of the southern slopes of the Catalina Mountains listed 700 plant species (those above 2743 m being from the southern slopes of the Pinaleno Mountains), but they did not report these plant occurrences relative to specific biomes as we do in this preliminary study. Instead, they

reported them relative to a large matrix of environmental variables and growth forms. Although we do not use that approach here (we are interested in documenting plant species associated with our arthropod transect sites), the ASAP project is collecting detailed environmental data and may undertake such an analysis in the future as relevant to arthropod species and communities. Also, none of the publications by Whittaker, Niering, or Lowe analyzed plant occurrences statistically in the Catalina Mountains relative to elevation or biome.

After classifying sites according to biome using the categorical system previously described, we used a series of analysis of similarity (ANOSIM) tests as implemented in PRIMER 5.2.9 (Clarke and Gorley 2001) to ask if the plant communities in these biomes significantly differ from one another. We calculated the Bray-Curtis distance among all possible pairs of sites based on species composition and abundance of the 77 species of trees, perennial woody shrubs, and succulents found in our sites. We then used ANOSIM to establish overall differences among plant biomes, followed by a series of pairwise biome comparisons. To visualize the relationships among sites we provide the multidimensional scaling (MDS) ordination plot (fig. 4). ANOSIM revealed significant overall differences in plant community composition among biomes ($R = 0.858$, $P < 0.001$). Furthermore, pairwise comparisons indicate that all plant biomes significantly differ from one another, which suggests that our classification system does identify sites that are unique with regard to their plant assemblages. Oak-Woodland sites were excluded from these analyses because of the low sample size (two sites). To the best of our knowledge, the ANOSIM analysis of our 66 sites based on plant abundance and species composition is the first statistical analysis of plant distributions in this range.

Table 6—Biomes sampled in the Santa Catalinas, with numbers of plant species recorded from transects in each.

Biome ^a	Common species ^b	Uncommon species ^c	Total species	Elevation range sampled
Desertscrub (S) 5 transect sites	44	30	74	1045-1172 m (3428-3845 ft)
Desert Grassland (N) 5 transect sites	61	70	131	1330-1645 m (4364-5397 ft)
Grazing-Disturbed Grassland (N) 7 transect sites	51	48	99	1323-1451 m (4340-4760 ft)
Oak-Grassland (S) 6 transect sites	52	36	88	1384-1433 m (4541-5030 ft)
Oak Woodland (N) 2 transect sites	9	21	30	1939-2000 m (6362-6562 ft)
Chaparral (N) 5 transect sites	32	22	54	1845-1971 m (6053-6467 ft)
Chaparral (S) 2 transect sites	10	17	27	1923-2052 m (6309-6732 ft)
Pine-Oak Woodland (N) 5 transect sites	29	17	46	2032-2149 m (6667-7051 ft)
Pine-Oak Woodland (S) 7 transect sites	26	24	50	1803-2422 m (5915-7946 ft)
Pine Forest (N) 4 transect sites	10	13	23	2218-2305 m (7277-7562 ft)
Pine Forest (S) 8 transect sites	25	20	45	2224-2463 m (7297-8081 ft)
Mixed Conifer Forest (MTN) 10 transect sites	24	19	43	2442-2777 m (8012-9111 ft)

^a N = northern slopes of range (along Control Road). S = southern slopes of range (along Mt. Lemmon Highway). MTN = Mt. Lemmon and Mt. Bigelow sites.

^b “Common Species” are species found in two or more transects in the given biome.

^c “Uncommon Species” are species recorded from only a single transect in the given biome.

Table 7—List of plant species found in each biome for Catalinas Transects 2011 arthropod survey. DS = Desertscrub. DG = Desert Grassland. DDG = Grazing Disturbed Desert Grassland. OG = Oak Grassland. OW=Oak Woodland. C = Chaparral. PO = Pine-Oak Woodland. P = Pine Forest. MC = Mixed Conifer Forest. (S) = South side transects. (N) = North side transects. (MTN) = Mt. Lemmon and Mt. Bigelow transects.

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Abies bifolia</i> var. <i>arizonica</i>	corkbark fir												C
<i>Abies concolor</i>	white fir											C	C
<i>Abutilon coahuilae</i>	caliche Indian mallow		U	C									
<i>Abutilon incanum</i>	Indian mallow	U											
<i>Acacia angustissima</i>	fern acacia	U	U		C								
<i>Acacia constricta</i>	whitethorn acacia		C	C	U								
<i>Acacia greggii</i>	catclaw acacia	C	U	C									
<i>Acalypha neomexicana</i>	New Mexico copperleaf		C	U	C		U						
<i>Acer glabrum</i>	Rocky Mountain maple												U
<i>Acer grandidentatum</i>	bigtooth maple												C
<i>Achillea millefolium</i>	common yarrow										U	U	
<i>Acourtia wrightii</i>	brownfoot												
<i>Adenophyllum porophylloides</i>	San Felipe fetid marigold	U											
<i>Agave chrysantha</i>	golden-flower agave	U	C	C		C	C	C					
<i>Agave schottii</i>	shindagger agave	C			C								
<i>Allionia incarnata</i>	desert windmills	C	C	U									
<i>Alnus oblongifolia</i>	alder												U
<i>Aloysia wrightii</i>	lemon verbena	C	C	C									
<i>Amaranthus</i> nr. <i>palmeri</i>	amaranth		C	U	C		U						
<i>Amaranthus fimbriatus</i>	fringed amaranth			U									
<i>Ambrosia ambrosioides</i>	canyon ragweed	C											
<i>Ambrosia confertiflora</i>	slimleaf ragweed	C	C	C									
<i>Amorpha fruticosa</i>	false indigobush											U	
<i>Andropogon</i> sp.	Poaceae		U				U						
<i>Anoda cristata</i>	spurred anoda		U										
<i>Aquilegia chrysantha</i>	golden columbine											U	C
<i>Arbutus arizonica</i>	Arizona madrone							C	U	U			
<i>Arceuthobium vaginatum</i>	pineland dwarf mistletoe									U	C	U	
<i>Arctostaphylos pungens</i>	pointleaf manzanita		C	U	C	U	C	C		C			
<i>Arenaria lanuginosa</i> ssp. <i>saxosa</i>	sandwort		U						C				
<i>Argemone pleiacantha</i>	prickly poppy		U	U									
<i>Aristida adscencionis</i>	six-weeks three awn			U	U								
<i>Aristida purpurea</i>	purple three-awn		C	C	U			U					
<i>Aristida ternipes</i> var. <i>ternipes</i>	spidergrass	C	C	C	C		C	C					
<i>Aristolochia watsonii</i>	southwestern pipevine			C									
<i>Artemisia ludoviciana</i>	white sagebrush		U			U	U						
<i>Artemisia</i> sp.	wormwood; Asteraceae											U	
<i>Asclepias asperula/engelmanniana</i>	milkweed												
<i>Asclepias hypoleuca</i>	mahogany milkweed								C		U		
<i>Astragalus</i> sp.	locoweed; Fabaceae				U								
<i>Ayenia compacta</i>	ayenia	C											
<i>Baccharis sarothroides</i>	desert broom		C		C								
<i>Baccharis</i> sp.	broom; Asteraceae			C									
<i>Bahia absinthifolia</i>	hairy bahia	C	C	U									
<i>Boerhavia</i> sp.	spiderling; Nyctaginacea	U	C	C	C								
<i>Bommeria hispida</i>	copper fern		U										
<i>Bothriochloa barbinodis</i>	cane beardgrass		C	U	C								
<i>Bouteloua barbata</i> var. <i>rothrockii</i>	Rothrock grama	U											
<i>Bouteloua chondrosioides</i>	sprucetop grama		U	U									
<i>Bouteloua curtispindula</i>	side-oats grama	C	C	C	C		C						
<i>Bouteloua gracilis</i>	blue grama		U										
<i>Bouteloua hirsuta</i>	hairy grama												

Cont.

Table 7—Continued

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Bouteloua repens</i>	slender grama	U											
<i>Bouvardia ternifolia</i>	scarlet bouvardia				C		U						
<i>Brickellia baccharidea</i>	resin-leaf brickellbush			U									
<i>Brickellia californica</i>	California brickellbush				C		C	C	U	U			
<i>Brickellia</i> nr. <i>diffusa</i>	brickellbush									C			
<i>Brickellia coulteri</i>	brickellbush	C											
<i>Brickellia</i> sp.	brickellbush								C		U	C	
<i>Bromus rubens</i>	red brome			C									
<i>Bromus</i> sp.	brome; Poaceae											U	C
<i>Calliandra eriophylla</i>	fairy duster	C	C	C									
<i>Carnegiea gigantea</i>	saguaro	C											
Caryophyllaceae			U										
<i>Castilleja chromosa</i>	Indian paintbrush											U	U
<i>Ceanothus fendleri</i>	Fendler buckbrush					C	C	U	C	C	C	C	
<i>Celtis pallida</i>	desert hackberry	C											
<i>Cercocarpus montanus</i>	mountain mahogany					U	C						
<i>Chamaecrista nictitans</i>	partridge pea		C		C								
<i>Chamaesyce arizonica</i>	Arizona sandmat		U										
<i>Chamaesyce</i> sp. <i>C. revoluta</i> , or <i>C. gracillima</i>	sandmat; Euphorbiaceae				U								
<i>Cheilanthes</i> nr. <i>yavapense</i>	graceful lipfern				C	U	U		C	U			
<i>Cheilanthes lindheimeri</i>	Lindheimer lipfern, fairy swords				C								
<i>Cheilanthes wrightii</i>	Wright's lipfern		U										
<i>Cheilanthes yavapense</i>	graceful lipfern												
<i>Chenopodium</i> sp.	Amaranthaceae		U										
<i>Cirsium arizonicum</i>	Arizona thistle							U	U	U			
<i>Cirsium neomexicanum</i>	New Mexico thistle		U	C	U								
<i>Cirsium</i> sp.	thistle; Asteraceae											C	
<i>Cologania angustifolia</i>	longleaf colognia		U										
<i>Commelina erecta</i>	whitemouth dayflower					U		C	U	U			
<i>Commicarpus scandens</i>	bush spiderling	U	U	U									
Composite with licorice smell	Asteraceae		U					U					
Composite with <i>Mentzelia</i> – shaped leaves	Asteraceae				U			U					
Composite with white rays	Asteraceae									U			
<i>Condalia warnockii</i> var. <i>kearneyana</i>	condalia			U									
<i>Coryza</i> sp.	Asteraceae										U		
<i>Coryphantha vivipara</i>	beehive cactus			C	C								
<i>Cupressus arizonica</i>	Arizona cypress				U		U						
<i>Cuscuta indecora</i>	dodder			U									
<i>Cuscuta</i> sp.	dodder; Convolvulaceae		U										
<i>Cylindropuntia bigelovii</i>	teddybear cholla	U											
<i>Cylindropuntia fulgida</i>	jumping cholla	C											
<i>Cylindropuntia leptocaulis</i>	desert Christmas cholla		U	U									
<i>Cylindropuntia spinosior</i>	cane cholla												
<i>Cylindropuntia versicolor</i>	staghorn cholla	C		U									
<i>Cyperus</i> sp.	Cyperaceae		U			U	U		C	C	U		
<i>Dalea albiflora</i>	whiteflower prairie clover		U		C		C						
<i>Dalea formosa</i>	feather plume			U									
<i>Dalea pulchra</i>	pea bush, Santa Catalina prairie clover, indigo bush	C											
<i>Dalea</i> sp.	upright herb; Fabaceae								U				
<i>Dasyilirion wheeleri</i>	sotol, desert spoon		C	C	C			C					
<i>Dasyochloa pulchella</i>	fluff grass			U									
<i>Datura wrightii</i>	sacred datura		U										
<i>Desmanthus</i> nr. <i>cooleyi</i>	bundleflower				U								
<i>Desmodium batocaulon</i>	bushy tick clover		C		C	U	C						
<i>Desmodium procumbens</i>	trailing tick clover				C								
<i>Dicliptera resupinata</i>	Arizona foldwing	U		C									
<i>Digitaria californica</i>	Arizona cottontop	U	U										

Cont.

Table 7—Continued

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Echeandia flavescens</i>	Torrey's craglily						U						
<i>Echinocereus bonkeræ</i>	Bonker hedgehog cactus												
<i>Echinocereus coccineus</i>	claret-cup hedgehog cactus		U		U				C				
<i>Echinocereus fasciculatus</i>	robust hedgehog cactus	C	C	U									
<i>Elymus elymoides</i>	squirreltail		U	C									
<i>Encelia farinosa</i>	brittlebush	C											
<i>Enneapogon mollis</i>	soft feather pappus grass				U								
<i>Eragrostis cilianensis</i>	stinkgrass		U										
<i>Eragrostis curvula</i>	weeping lovegrass	U					U						
<i>Eragrostis intermedia</i>	plains lovegrass		U				C		U				
<i>Eragrostis lehmanniana</i>	Lehmann lovegrass	C	C	C	C		C						
<i>Ericameria laricifolia</i>	turpentine bush	U	C	C	U								
<i>Erigeron arizonicus</i>	Arizona fleabane											U	C
<i>Erigeron divergens</i>	fleabane		U	U			U						
<i>Erigeron</i> sp.	upright form; Asteraceae								C				
<i>Eriogonum nr. abertianum</i>	Abert's buckwheat		U		U			U		U			
<i>Eriogonum wrightii</i>	buckwheat	U	C	C	C								
<i>Erythrina flabelliformis</i>	coral bean				C								
<i>Euphorbia florida</i>	spurge	C											
<i>Euphorbia heterophylla</i>	Mexican fireplant		C	U	C								
<i>Euphorbia hyssopifolia</i>	spurge		C	C	C								
<i>Euphorbia melanadenia</i>	spurge			C									
<i>Euphorbia polycarpa</i>	spurge			C									
<i>Evolvulus alsinoides</i>	Arizona blue eyes	C	C	U									
Fern; unknown genus	Pteridaceae												U
<i>Ferocactus wislizeni</i>	fishhook barrel cactus	C	C	C	U								
<i>Fouquieria splendens</i>	ocotillo	C	C	C									
<i>Fragaria</i> sp.	wild strawberry; Rosaceae											C	U
<i>Frangula californica</i>	California buckthorn, coffeeberry									C			
<i>Funastrum cynanchoides</i>	= <i>Sarcostemma cynanchoides</i> ; milkweed vine	U											
<i>Galactia wrightii</i>	rock bean, Wright's milkpea	U	C										
<i>Galium aparine</i>	bedstraw	U	U										
<i>Galium fendleri</i>	bedstraw								C			C	C
<i>Galium</i> sp.	bedstraw; Rubiaceae		U		C	U	U						
<i>Garrya wrightii</i>	silk-tassel bush				C	U	C	U		C			
<i>Geranium caespitosum</i>	pineywoods geranium								U			C	C
<i>Glandularia bipinnatifida</i>	small-flowered verbena, Dakota mock vervain		U				C						
<i>Gomphrena caespitosa</i>	tufted globe amaranth						C						
<i>Goodyera oblongifolia</i>	rattlesnake plantain								U	U	U		
<i>Guardiola platyphylla</i>	Apache plant				U								
<i>Gutierrezia</i> sp.	snakeweed; Asteraceae						U	U					
<i>Gymnosperma glutinosum</i>	gumhead					U		U					
<i>Haplophyton camicidum</i> var. <i>crooksii</i>	cockroach plant	U											
<i>Hedeoma</i> nr. <i>hyssopifolia</i>	mock pennyroyal				U	U	U		U	C		U	U
<i>Helianthella quinquenervis</i>	nodding dwarf sunflower		U							U		C	U
<i>Helianthus</i> sp.	wild sunflower; Asteraceae					U							
<i>Heliomeris longifolia</i> ssp. <i>annua</i>	longleaf false goldeneye			U			C						
<i>Heliopsis annua</i>			C		U				C				
<i>Hesperidanthus linearifolius</i>	slimleaf plainsmustard				U					C			
<i>Heteropogon contortus</i>	tanglehead		C	U	C								
<i>Heterotheca psamophila</i>	camphorweed				C								
<i>Heuchera sanguinea</i>	coralbell								U				
<i>Hibiscus coulteri</i>	Coulter hibiscus	C											
<i>Hilaria belangeri</i>	curly mesquite grass		U	C									
<i>Hymenopappus filifolius</i>	fineleaf woollywhite						C	U					
<i>Hymenopappus</i> sp.	Asteraceae						U						

Cont.

Table 7—Continued

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Hymenothrix wislizeni</i>	Trans-Pecos thimblehead			U									
<i>Ipomoea barbatisepala</i>	canyon morning glory		U	U									
<i>Ipomoea cristulata</i>	scarlet creeper		C		C								
<i>Ipomoea leptotoma</i>	triple-leaf morning glory			U									
<i>Ipomoea</i> sp.	morning glory vine; Convolvulaceae	C	C	C			U						
<i>Isocoma tenuisecta</i>	burweed		U	C	U								
<i>Jamesia americana</i>	cliff bush												C
<i>Janusia gracilis</i>	desert vine	C											
<i>Jatropha cardiophylla</i>	limberbush	C											
<i>Juniperus arizonica</i>	red-berry juniper			U									
<i>Juniperus deppeana</i> var. <i>deppeana</i>	alligator juniper		U		U	C	C		C	C	U		
<i>Justicia longii</i>	white needle flower	C											
<i>Kallstroemia californica</i>	caltrop				C								
<i>Kallstroemia californica</i> or <i>parviflora</i>													
<i>Kallstroemia grandiflora</i>	Arizona poppy		U	U									
<i>Koeleria macrantha</i>	junegrass								U				
<i>Krameria erecta</i>	range ratany		U	U									
<i>Krameria lanceolata</i>	trailing ratany			C									
<i>Laennecia schiedeana</i>	Asteraceae								C	C			
<i>Lathyrus</i> sp.	pea; Fabaceae											C	C
<i>Lepidium</i> sp.	Brassicaceae									U			
<i>Leptochloa dubia</i>	green sprangletop												
<i>Leptochloa fiscal</i> ssp. <i>uninervia</i>													
<i>Linum neomexicanum</i>	New Mexico yellow flax					U			C	U			
<i>Lotus</i> sp.	fine-leaf form; Fabaceae		U		U				C	U	U		
<i>Lotus greenei</i>	Greene's lotus						C		C	C	C		
<i>Lotus</i> sp.	Fabaceae				C	U	C		C		C		
<i>Lupinus</i> sp.	lupine; Fabaceae											U	
<i>Lycium berlandieri</i>	wolfberry	C											
<i>Lycium fremontii</i>	wolfberry	C											
<i>Lycium pallidum</i>	wolfberry		U	U									
<i>Lycium</i> sp.	wolfberry; Solanaceae	U	U										
<i>Machaeranthera tortifolia</i>	Asteraceae			C									
<i>Maianthemum racemosum</i>	false Solomon's seal												U
<i>Malaxis tenuis</i>	adder's tongue									C			C
<i>Mammillaria grahamii</i>	fishhook pincushion cactus	C											
<i>Mammillaria heyderi</i>	cream cactus, pincushion cactus		U										
<i>Marina</i> nr. <i>diffusa</i>	spreading false prairie clover					C	C		C		C		
<i>Marrubium vulgare</i>	horehound			U									
<i>Menodora scabra</i>	twinfruit	U											
<i>Mentzelia</i> sp.	Loasaceae				U								
<i>Mimosa aculeaticarpa</i>	wait-a-minute bush	C	C	C	C	U	U						
<i>Mirabilis laevis</i>	desert four o'clock	C											
<i>Mirabilis</i> sp.	Nyctaginaceae							U	C	C			
<i>Mirabilis</i> sp. <i>Oxybaphus</i> -type	Nyctaginaceae									U			
<i>Monarda</i> sp.	Lamiaceae				U								
<i>Monotropa hypopitys</i>	pinetop												U
<i>Muhlenbergia alopecuroides</i>	wolftail		U		U		C						
<i>Muhlenbergia emersleyi</i>	bullgrass		C		C	C	C	C	C	C	C	U	
<i>Muhlenbergia fragilis</i>	delicate muhly		U										
<i>Muhlenbergia porteri</i>	bush muhly	C		C									
<i>Muhlenbergia</i> sp. 1	Poaceae				U					U			
<i>Muhlenbergia</i> sp. 2	Poaceae						U						
<i>Nolina microcarpa</i>	beargrass		U	U	C	U	C	C		U			
<i>Oenothera</i> sp.	evening primrose; Onagraceae											U	

Cont.

Table 7—Continued

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Opuntia engelmannii</i>	Engelmann prickly pear cactus	C	C	C	C								
<i>Opuntia engelmannii</i> X <i>O. phaeacantha</i>	hybrid	U											
<i>Opuntia phaeacantha</i> var. <i>major</i>	sprawling prickly pear cactus	C		C	U								
<i>Oxalis</i> sp.	Oxalidaceae											U	
<i>Packera neomexicana</i>	New Mexico groundsel					U			C	C	U	C	U
<i>Panicum hirticaule</i>	Mexican panic grass		C	U	C								
<i>Parkinsonia florida</i>	blue palo verde	C											
<i>Parkinsonia microphylla</i>	foothills palo verde	C											
<i>Pellaea</i> sp.	Pteridaceae					U	C			U			
<i>Penstemon barbatus</i>	scarlet bugler						C			C		C	
<i>Penstemon eatonii</i>	firecracker penstemon		U										
<i>Penstemon pseudospectabilis</i>	desert penstemon						C						
<i>Phaseolus maculatus</i> ssp. <i>ritensis</i>	spotted bean							U					
<i>Phaseolus parvulus</i>	wild bean		U		C					C			
<i>Phaseolus</i> sp.	bean; Fabaceae											C	U
<i>Phemeranthus aurantiacus</i>	flame flower	U	C	C	U								
<i>Phoradendron californicum</i>	desert mistletoe	U											
<i>Physalis crassifolia</i>	ground cherry	U											
<i>Physalis hederifolia</i> var. <i>fendleri</i>	Fendler's ground cherry		U	C			U						
<i>Physalis</i> sp.	tiny flowers; Solanaceae		U										
<i>Pinus chihuahuana</i>	Chihuahua pine					C			C	C			
<i>Pinus discolor</i>	= <i>Pinus cembroides</i> var. <i>bicolor</i> ; border pinyon pine							C		U			
<i>Pinus ponderosa</i> var. <i>scopulorum</i> / <i>P. arizonica</i>	Rocky Mountain ponderosa pine/Arizona Pine								C	C	C	C	C
<i>Pinus strobiformis</i>	southwestern white pine								U	C	C	C	C
Polemoniaceae	phlox family						U		U				
<i>Polygala</i> sp.	milkwort; Polygalaceae				U			U					
<i>Populus tremuloides</i>	quaking aspen											U	C
<i>Porophyllum gracile</i>	odora, yerba de venado	U											
<i>Porophyllum ruderale</i>	yerba porosa		C	U	C								
<i>Portulaca oleracea</i>	common purslane	U	U	C	C								
<i>Portulaca pilosa</i>	kiss me quick	U	C	C	C								
<i>Portulaca umbraticola</i>	Chinese hat		C	U	C								
<i>Potentilla thurberi</i>	scarlet cinquefoil									U			
<i>Prosopis velutina</i>	= <i>Prosopis juliflora</i> var. <i>velutina</i> ; velvet mesquite												
<i>Prunus virginiana</i>	chokecherry									U		U	
<i>Pseudocymopterus montanus</i>	mountain parsley											C	C
<i>Pseudognaphalium</i> sp.	cudweed; Asteraceae		C		C		C		C	C	U	U	
<i>Pseudotsuga menziesii</i> var. <i>glauca</i>	Rocky Mountain Douglas-fir								C	C	C	C	C
<i>Psilostrophe cooperi</i>	whitestem paperflower		U										
<i>Pteridium aquilinum</i>	bracken fern								U		U	C	C
<i>Quercus arizonica</i>	Arizona white oak		C	U	C	C	C		C			C	
<i>Quercus emoryi</i>	Emory oak		C		C	U	C	U		U			
<i>Quercus gambelii</i>	Gambel oak											C	C
<i>Quercus hypoleucoides</i>	silverleaf oak					C	C	C	C	C	C	C	U
<i>Quercus oblongifolia</i>	Mexican blue oak				U								
<i>Quercus turbinella</i>	scrub oak			U									
<i>Rhamnus crocea</i>	hollyleaf buckthorn		U	U		U							
<i>Rhus aromatica</i>	skunkbush		U	U									
<i>Robinia neomexicana</i>	New Mexico locust							U	U	U		C	C
<i>Rubus neomexicanus</i>	New Mexico raspberry											U	C
<i>Rubus</i> sp.	smaller; Rosaceae												C
<i>Rubus</i> sp.	raspberry-like; Rosaceae												U
<i>Rumex</i> sp.	dock; Polygonaceae												U

Cont.

Table 7—Continued

		DS (S)	DG (N)	DDG (N)	OG (S)	OW (N)	C (N)	C (S)	PO (N)	PO (S)	P (N)	P (S)	MC (MTN)
<i>Salvia</i> sp.	Lamiaceae		U										
<i>Sarcostemma crispum</i>	climbing milkweed				U								
<i>Scrophularia parviflora</i>	pineland figwort											U	U
<i>Selaginella arizonica</i>	spike moss	U											
<i>Selaginella rupincola</i>	rockloving spike moss				U								
<i>Senna bauhinioides</i>	twinleaf senna		C	C									
<i>Senna covesii</i>	desert senna	C											
<i>Setaria leucopila</i>	bristlegrass			U									
<i>Sida abutilifolia</i>	spreading fanpetals			U									
<i>Solanum eleagnifolium</i>	horse nettle			C									
<i>Solanum</i> sp.	Solanaceae								U				
<i>Solidago wrightii</i>	goldenrod					U	U		C	C	C	C	U
<i>Sphaeralcea fendleri</i>	Fendler's globe mallow							U					
<i>Sphaeralcea laxa</i>	caliche globe mallow	C	U	C	U								
<i>Sphinctospermum constrictum</i>	hourglass peaseed				U								
<i>Sporobolus airoides</i>	alkali sacaton			U									
<i>Stemodia durantifolia</i>	whitewooly twintip		U		U		U						
<i>Stephanomeria pauciflora</i>	wire lettuce												
<i>Stevia</i> sp.	Asteraceae												U
<i>Symphoricarpos oreophilus</i>	mountain snowberry											C	C
<i>Thalictrum fendleri</i>	meadow rue								C			U	C
<i>Thamnosoma</i> sp.	Rutaceae		U										
<i>Thymophylla pentachaeta</i>	dogweed		U		U								
<i>Tradescantia pinetorum</i>	pinewoods spiderwort									U			
<i>Tragia nepetifolia</i>	catnip noseburn	U											
<i>Trichostema arizonicum</i>	Arizona blue curls				C								
<i>Tridens muticus</i>	slim tridens	C	U	U									
Unknown composite	fernlike leaves												
<i>Urochloa arizonica</i>	Arizona panic grass	C	C	U	C								
<i>Verbascum thapsus</i>	common mullein								U	U			
<i>Verbena neomexicana</i>	hillside vervain		U	U									
<i>Verbesina encelioides</i>					U								
<i>Vicia</i> sp.	vetch; Fabaceae								U			U	U
<i>Viola</i> sp.	violet; Violaceae									U		C	C
white-backed fern	Pteridaceae		U										
<i>Xanthisma gracilis</i>	slender goldenweed		U	U									
<i>Xanthisma spinulosa</i>	spiny goldenweed		U										
<i>Xylorhiza tortifolia</i>	Mojave woodyaster				C								
<i>Yucca elata</i>	soaptree yucca			C									
<i>Yucca madrensis</i>	mountain yucca		U		C	C	C	U	C	C	U		
<i>Zinnia acerosa</i>	desert zinnia	U	U	U									
<i>Ziziphus obtusiflora</i>	graythorn		U	C									
<i>Zornia latifolia</i>			U										

Plant diversity data are summarized in tables 6 and 7. The highest plant diversity occurred in our Desert Grassland sites on the north side of the Catalina Mountains, where the relatively undisturbed transect sites had a total of 131 species and the grazing-disturbed sites had a total of 99 species. This was followed by the southern slope Oak-Grassland sites with 88 species, and the Desertscrub sites with 74 species. Pine-Oak Woodland sites had 46 plant species (northern slopes) and 50 species (southern slopes). The lowest diversity sites were Pine Forest of the northern slopes (23 species) and Chaparral on the southern slopes (27 species). This is the same biome diversity trend noted by Whittaker and Niering (1965) and other workers over the years. A number of our plant records are new species to the Catalina Mountains, or significant elevation extensions, and these will be discussed in future papers.

Desertscrub—Because the base of the Catalina Mountains on its northern side is ~1220 m, there is no Desertscrub. Instead, the biome at the base (the start of the Control Road, in the town of Oracle) is Grassland. However, a well-developed Arizona Upland Desertscrub is at the base of the mountain on the south side, and it contains all of the signature plants of this Sonoran Desert subprovince (table 7). Whittaker and Niering (1965) called this the “Sonoran Desert of Mountain Slopes” biome, even though Forrest Shreve had coined the well-accepted name Arizona Upland in 1951 for this subprovince of the Sonoran Desert. Three of our Desertscrub sites are near Babad Do’ag Viewpoint, along the Babad Do’ag Trail. Because of its elevation (1133–1160 m) and proximity to the opening of Molino Canyon, the Babad Do’ag sites are wetter than the other Desertscrub site (1045 m), and thus velvet mesquite (*Prosopis velutina*) and desert

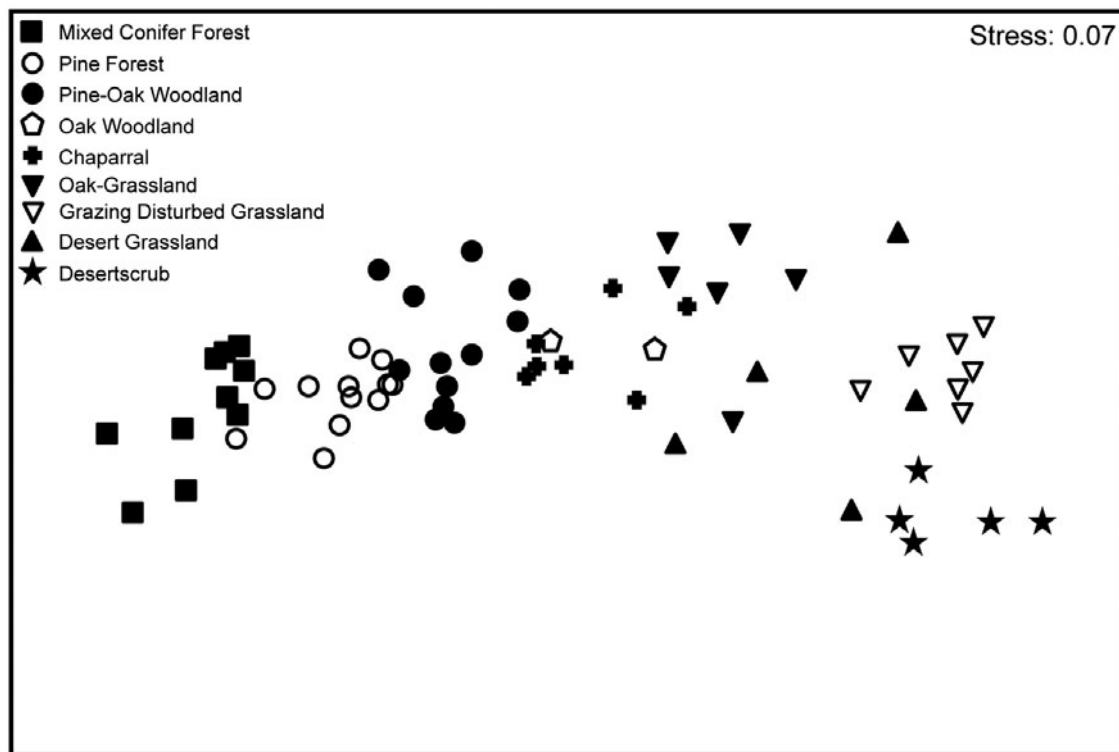


Figure 4—MDS ordination of sites based on Bray-Curtis similarity values. Sites were classified according to the composition and abundance of 77 species of trees, perennial woody shrubs, and succulents found in the transect sites. Plant biome designations for each site were determined a-priori using the criteria outlined in this paper. Note that the MDS ordination shown in this figure is a 2-dimensional compression of a multi-dimensional clustering of the sites, so graphical representation is not perfect. However, the stress value of 0.07 indicates that information in the 2-dimensional figure does a good job of describing patterns in the multi-dimensional space.

hackberry (*Celtis pallida*) are present (and palo verde/*Parkinsonia* sp. and saguaro/*Carnegiea gigantea* are fewer in number); also shindagger agave (*Agave schottii*), turpentinebush (*Ericameria laricifolia*), limberbush (*Jatropha cardiophylla*), sprawling prickly pear (*Opuntia phaeacantha* var. *major*), and many wildflowers. For example, purple ground cherry (*Physalis crassifolia*), desert windmills (*Allionia incarnata*) and spike moss (*Selaginella arizonica*) occur at this wetter site, indicative of its proximity to the transition into Grassland habitat. Although none of our transects had invasive buffelgrass (*Pennisetum ciliare*), large patches of it occur across the Desertscrub landscape on the southern slopes of the Catalina Mountains and in the Babad Do'ag Trail area large patches of invasive Lehmann lovegrass (*Eragrostis lehmanniana*) also are found. Desertscrub habitat extends to ~1177 m on the southern slopes of the Catalina Mountains along the Mt. Lemmon Highway.

Undisturbed Savanna-like Habitats: Desert Grassland and Oak-Grassland—About half the plant species found in these two savanna-like biomes are shared, so we discuss them together. There are no large swaths of Desert Grassland along the Mt. Lemmon Highway on the south side of range, and there Desertscrub transitions quickly into Oak-Grassland dominated by Emory oak, Arizona white oak, and four grasses - side-oats grama (*Bouteloua curtipendula*), cane beardgrass (*Bothriochloa barbinodis*), Arizona panic grass (*Urochloa arizonica*), and the elevationally wide-ranging bullgrass (*Muhlenbergia emersleyi*) (a total of 14 grasses were recorded in our Oak-Grassland transects). Other abundant plants of our Oak-Grassland sites are pointleaf man-

zanita (*Arctostaphylos pungens*), shindagger agave, sotol (*Dasyilirion wheeleri*), beargrass (*Nolina microcarpa*), mountain yucca (*Yucca madrensis*), scarlet creeper (*Ipomoea cristulata*), Amaranth (*Amaranthus* nr. *palmeri*), and three species of *Portulaca*. Although our Grassland and Oak-Grassland sites share many species, each also has many unique components (table 7). The transition between Grassland and Oak-Grassland biomes is most easily seen in the turnover of grass species along elevational gradients and the increasing abundance of oaks with higher elevations. Although Arizona white oak (*Quercus arizonica*) and manzanita make their first appearance in these grassy habitats, these are elevationally broad-ranging plants that are also found in Chaparral, Oak Woodland, and Pine-Oak Woodland. In contrast to the southern slopes, the north side of the Catalina Mountains has accessible, expansive, rolling hills of Desert Grassland but no well-developed Oak-Grassland (along the Control Road). These north-side Desert Grassland sites harbored 131 plant species, making this the most botanically diverse biome in our study, including 22 grass species, although 4 species dominated in abundance: side-oats grama, Arizona panic grass, Mexican panic grass (*Panicum hirticaule*), and the invasive Lehmann lovegrass. In addition to these grasses, velvet mesquite, whitethorn acacia (*Acacia constricta*), wait-a-minute bush (*Mimosa aculeaticarpa*), fairy duster (*Calliandra eriophylla*) were all present in high numbers, indicative of some history of grazing disturbance. On Grassland sites with strong limestone presence, the most abundant plants included a half-dozen typical Desertscrub species, with ocotillo (*Fouquieria splendens*) dominating. Ground cover

by grasses was high in all Desert Grassland transects, often 90%, and sometimes dominated by the invasive Lehmann's lovegrass.

Grazing-Disturbed Grassland—On the north side of the Catalina Mountains, most Grassland habitats have been converted to “scrubland” by over a century of grazing, giving the landscape a desert-like appearance. Seven transects were established in this highly disturbed Desert Grassland near the base of the mountain along the Control Road, from 1337 to 1451 m. All of these sites showed evidence of decades of heavy livestock traffic, with a great deal of disturbed, bare dirt and disrupted soil and, in some areas, erosion down to bedrock. These transects had 99 plant species that were a mix of Desert Grassland and Desertscrub species characteristic of long-overgrazed Grasslands of southeastern Arizona. Typical invasive native Desertscrub plants included velvet mesquite, whitethorn acacia, catclaw acacia (*Acacia greggii*), fishhook barrel cactus (*Ferocactus wislizeni*), slim ragweed (*Ambrosia confertiflora*), and fairy duster, and the abundance and biomass of these species generally exceeded that of the Grassland species. The large number of grass species (19) in these disturbed sites might be due, in part, to the history of livestock grazing and imported forage. This was the only site where we found red brome (*Bromus rubens*), an exotic invasive grass.

Oak Woodland—Oak Woodland is generally characterized by stands of oaks, with junipers and pinyons. This biome reaches its maximum development in the Sierra Madre of Mexico, and in general, more northern Sky Islands have less Oak Woodland than more southern ranges. In the Catalina Mountains, well-developed Oak Woodland does not occur along the Mt. Lemmon Highway, on the south side of the mountains. However, on the north side of the Catalina Mountains, patches of Oak Woodland do occur along the Control Road, and in our two transect sites in this habitat there was a total of 30 plant species (tables 6 and 7). Seven of the nine signature species of this biome listed by Whittaker and Niering (1968b) occurred in our site transects. These woodlands are dense with foliage, the large dominants being Arizona white oak, silverleaf oak, Chihuahua pine (*Pinus chihuahuana*), alligator juniper (*Juniperus deppeana*), and Fendler buckbrush (*Ceanothus fendleri*). Bullgrass covers much of ground between the trees. In the Catalinas, the elevationally broadly occurring alligator juniper, Fendler buckbrush, and adder's tongue make their first appearances in Oak Woodlands and are then found all the way into Pine Forest habitat and in the case of adder's tongue into the Mixed Conifer Forest.

Chaparral—Interior Chaparral occurs on both the north and south sides of the Catalina Mountains, but it is more extensively developed along the Control Road on the northern slopes. Our Chaparral sites on the south side of the range had 27 plant species, whereas the northern sites had 54. Even though the plant diversity on the north-side sites was greater, neither border pinyon nor sotol were found in those transect sites. The north-side Chaparral transects had abundant alligator juniper, Arizona white oak, Emory oak (*Quercus emoryi*), Fendler buckbrush, mountain mahogany (*Cercocarpus montanus*), silktassel bush (*Garrya wrightii*), and mountain yucca—all missing from the more depauperate south-side sites (tables 6 and 7). This is not to say these typical Chaparral plants do not occur on the southern slopes of the Catalina Mountains; they do, but just not in our transect sites. Virtually all of the Chaparral along the Mt. Lemmon Highway was burned in the 2003 Aspen fire, including our two south-side transect sites (near Manzanita Vista and Windy Point Vista), and it is likely this was at least partly the reason these sites were depauperate relative to those on the north side of the mountains (none of our five north-side Chaparral sites burned in the Aspen Fire). These south-side plant communities are only now beginning to show strong recovery. Chaparral

transects on both sides of the range were dominated by pointleaf manzanita, silverleaf oak, golden-flower agave (*Agave chrysantha*), beargrass, and spidergrass (*Aristida ternipes* var. *ternipes*). Higher plant diversity in the north-slope sites is likely also due to the greater variety of soil types there, including limestone soils. Whittaker and Niering (1965) and others have shown that limestone soils shift plant biomes upward on Sky Island mountains, such that at elevations where Grassland would normally occur one finds Desertscrub plants (with a strong presence of limestone-loving species such as ocotillo). This shift presumably occurs because limestone is porous and does not retain moisture, creating a more xeric soil condition that Desertscrub plants are adapted to. Several of our Chaparral sites were on limestone soils and these showed the expected up-elevation shift in Desertscrub plants.

Pine-Oak Woodlands—Our Pine-Oak Woodland transects had a total of 50 species (south slopes) and 46 species (north slopes). Abundant on both slopes were alligator juniper, Chihuahua pine, Rocky Mountain ponderosa pine/Arizona pine, Rocky Mountain Douglas-fir (*Pseudotsugamenziesii* var. *glauca*), silverleaf oak, Fendler buckbrush, mountain yucca, cudweed (*Pseudognaphalium* sp.), New Mexico groundsel (*Packera neomexicana*), goldenrod (*Solidago wrightii*), and bullgrass. It is here that Rocky Mountain Douglas-fir and Rocky Mountain ponderosa pine/Arizona pine make their first appearance in the Catalina Mountains, to continue all the way into Mixed Conifer Forest. Silverleaf oak, with its broad elevational range, occurs from Pine-Oak Woodland and Chaparral well into Pine Forest habitat. All six of Whittaker and Niering's (1968b) signature plant species of Pine-Oak Woodland occurred in our transect sites.

Pine Forest—Our Pine Forest transect sites had a total of 45 species (south slopes) and 23 species (north slopes). Abundant on both slopes were Rocky Mountain ponderosa pine/Arizona pine, southwestern white pine (*Pinus strobiformis*), Rocky Mountain Douglas-fir, silverleaf oak, Fendler buckbrush, brickellbush (*Brickellia* sp.), butterweed, goldenrod, pineland dwarf mistletoe (*Arceuthobium vaginatum*), cudweed, bracken fern (*Pteridium aquilinum*), and bullgrass. Although white fir occurred in some of the south-side Pine Forest transects, this tree is more typical of the Mixed Conifer Forest and did not occur below 2255 m in our transects. Rocky Mountain ponderosa pine/Arizona pine was dominant conifers in both the Pine Forest and Mixed Conifer biomes. Whittaker and Niering (1968b) noted five signature plant species of Pine Forest, although two were lower-elevation transitionals to Pine-Oak Forest/Woodland, and all but one of these (their transitional netleaf oak/*Quercus rugosa*) also occurred in our Pine Forest transects. It is in the upper Pine-Oak Woodland and Pine Forest biomes that ponderosa Pine Forests dominate the visual landscape of the Catalina Mountains and most of Arizona's other high Sky Islands.

Mixed Conifer Forest—Transect sites in our Mixed Conifer Forest sites, on Mt. Lemmon and Mt. Bigelow, at 2442–2777 m had 43 species (tables 6 and 7). Dominants, in terms of numbers of individuals, were Rocky Mountain ponderosa pine/Arizona pine, white fir (*Abies concolor*), southwestern white pine, Rocky Mountain Douglas-fir, pineywoods geranium (*Geranium caespitosum*), *Oxalis* sp. (an unidentified Oxalidaceae), mountain parsley (*Pseudocymopterus montanus*), bracken fern, meadow rue (*Thalictrum fendleri*), and *Viola* spp (an unidentified violet). Corkbark fir, which is rare south of the Mogollon Rim, occurred in only 2 of our 10 Mixed Conifer Forest transects. There are no naturally occurring spruces (*Picea*) in the Santa Catalina Mountains, and probably also no limber pine (*Pinus flexilis*), a more northern species, despite some old (dubious) records from the Catalina Mountains. Whittaker and Niering (1964)

and Whittaker and others (1968) subdivided the Mixed Conifer Forest into two elevational zones, “montane fir forest” and “subalpine Forest” (above 2440 m/8000 ft). They distinguished their “montane fir forest” biome by six species that occurred on our sampling transects.

Summary

The Arizona Sky Island Arthropod Project (ASAP) was launched in 2011. Parameters and over-arching goals of the project, and preliminary results of year one, are presented here. We define the boundaries of the Madrean Sky Island Region somewhat more broadly than they have been in the past, with less of an emphasis on the Madrean flora components and more of an emphasis on their location as isolated Cordilleran Gap ranges. The Mexican Sky Islands are still not well known and adjustments regarding the range and extent of the Sky Island Region will no doubt be fine tuned in the future. We point out the important difference between “mountain islands” vs. “habitat islands.” We present the first statistical analysis of plant species and biomes in the Santa Catalina Mountains, and use this to preliminarily establish the biome names and boundaries that we will use in our arthropod analyses. Year one ant and ground beetle (Carabidae) data for the Catalinas are presented; both groups are high in diversity (88 ant species, 69 ground beetle species) and show a trend of species affiliation to plant biomes.

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Composition of Ant Assemblages in the Santa Catalina Mountains,” and “Hidden Biodiversity of Sky Island Arthropods.”

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Preliminary Assessment of the Moth (Lepidoptera: Heterocera) Fauna of Rincon de Guadalupe, Sierra de Bacadéhuachi, Sonora, Mexico

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Abstract—The Sierra de Bacadéhuachi is a poorly sampled extension of the Sierra Madre Occidental (SMO) located in east-central Sonora near the town of Bacadéhuachi. Sampling of moths using mercury vapor and ultraviolet lights occurred in summer and fall 2011, and spring 2012 at Rincón de Guadalupe, located in pine-oak forest at 1680 m elevation. Approximately 400 taxa of moths were identified from this locality. Species occurrences demonstrate connections to the famously diverse Yécora area, to the higher, more mesic SMO in Chihuahua, as well as the Rocky Mountains to the north. Several unidentified and presumably new moth species from Rincón de Guadalupe await further study and description. Two species previously known only from the type specimens (destroyed in WWII) were rediscovered at Rincón de Guadalupe. A complete list of the moths identified from Rincon de Guadalupe is available as a Research Species List in the Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org).

Introduction

The Sierra de Bacadéhuachi is considered the westernmost massif of the Sierra Madre Occidental (SMO), and is located east of the Pueblo de Bacadéhuachi, Municipio de Bacadéhuachi, Sonora. While technically not a Sky Island, the range represents the northernmost extension of the SMO and serves as a conduit for SMO species to move north into the Sky Island region. Thus, species records from this area, of which there are historically few, are of interest to biologists working in the Sky Island region. The range is located only 34 km west of the border with Chihuahua, and 165 km south of the Arizona border. The Yécora plateau of the SMO is approximately 120 km to the SE. This area has historic significance as the location of Rincón de Guadalupe (RG), a rustic enclave of buildings constructed between 1920 - 1940 in the pine-oak forest on property owned by the Catholic Diocese of Sonora. The main facility located in Arroyo Campo Los Padres (29°50'40"N, 108°58'37"W, 1680 m elevation) was used as a base of operations for the field activities reported herein.

The Sierra de Bacadéhuachi vegetation ranges from lowland foothills thornscrub up through desert grassland to oak woodland and finally pine-oak forest. The area immediately around RG is dominated by pine and oak, and bisected by a perennial stream. Eleven species of *Quercus* and five species of *Pinus* are recorded from the area along with *Cupressus arizonica*, *Fraxinus velutina*, and *Platanus wrightii*. The most speciose families in the preliminary flora of the Sierra de

Bacadéhuachi are Asteraceae (54 taxa), Fabaceae (47 taxa), and Poaceae (36 taxa) (Van Devender and others, *Preliminary Flora of the Sierra Bacadéhuachi, Sonora, Mexico*, this volume).

Methods

A combination mercury vapor/ultraviolet light or ultraviolet light alone was used to attract the majority of moth species collected. A few exceptions, such as *Coloradia prchali*, were netted during the day. The light stations were run from dusk until dawn in the summer and fall when the nights remained warm, and until approximately 1AM in the spring after which it became too chilly for moths to fly. Sampling was conducted throughout the night and specimens were spread on site and dried in an oven to ensure as many different “cryptic” taxa as possible were recorded and to get representative examples of sexually dimorphic species for identification. In addition, several photographers documented diversity at the lights with photo vouchers of living moths, all of which are available records in the Madrean Archipelago Biodiversity Assessment (MABA) database (Madrean.org).

Results

About 400 species of moths were identified from all three sampling expeditions to Rincón de Guadalupe. Given that this collection represents only three periods of activity and a total of nine collecting nights in a single locality of the Sierra de Bacadéhuachi, the diversity of this area appears to be exceptionally rich. The total moth diversity for all areas and all months known from the Huachuca Mountains 170 km to the north is 1500 species— 900 “macrolepidoptera” (Powell and Opler 2009) and 600 “microlepidoptera.” This relatively well surveyed area (316 km²) is biologically diverse with vegetation ranging

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from desert grassland up to pine-oak forest in an elevational range of 1361 m (Bowers and McLaughlin 1966) similar to the Sierra de Bacadéhuachi. But given the strong influence and connections with the SMO, it is expected that further sampling of the Sierra de Bacadéhuachi in foothills thornscrub, desert grassland, and oak woodland along the 700 to 2370 m elevational gradient (range of 1670 m) at other times of the year will ultimately bring the number of moth taxa to well over that recorded for the Huachuclas.

Summer Sampling (July 31-August 3, 2011)

This initial sample during the monsoon period documented around 205 species. The number of tropical taxa more typically associated with tropical deciduous forest (TDF) was surprising. These included the extremely large tailed saturniid moth *Dysdaemonia boreas*, a common monsoon species in TDF where the larval foodplants in the family Bombacaceae occur, and another saturniid moth, *Copaxa multifenestrata*, which was previously thought to be restricted to extreme southeastern Sonora where the caterpillars are thought to feed on plants in the family Lauraceae. Also recorded were tropical sphingids *Xylophanes ceratomoides* and *X. tersa*, and one of the largest tropical sphinx moths, the *Forestiera*-feeding *Sphinx leucophaeta*. A single specimen of the metallic, tropical wasp-mimic tiger moth, *Phoenicoprocta lydia*, was also an unexpected record. Northern range extensions for several species more typical of the Yécora plateau (120 km to the south) were also significant new records: *Coloradia prchali* and *Copaxa muellerana*, (both Saturniidae), *Epicrisias eschara*, *Ammalo* nr. *paranomon*, and *Amastus* (two species; all Erebidae; Arctiinae) These records also reflect the association of this area with higher and more mesic regions in the SMO in Chihuahua to the east. A noteworthy southern record of the large silkmoth *Hyalophora gloveri* was also obtained for a Rocky Mountains species with only a handful of Sonoran records.

While noctuids (cutworm moths) were not particularly speciose in August, some of those that were collected were important records and several are thought to represent new and undescribed species. Unusual northern records include *Cropia europs*, *Dypterigia dolens* (both Noctuidae: Amphypirinae), *Coenipeta bibatrix* (Erebidae: Erebininae), and *Metria sinaloa* (Erebidae: Catocolinae). *Schinia simplex*, a lovely green noctuid (Heliiothinae) found in the Rocky Mountain region nearly to Canada, was an unexpected southern record, as there are no SE Arizona records of the species. A new species of *Richia* nr. *cofrensis* (Noctuidae: Noctuinae) was collected along with possibly new *Licnoptera* nr. *gulo*, a new *Panthea* nr. *gigantea* (both Noctuidae: Pantheinae), a new *Bryolymnia* nr. *biformata* and a new *Elaphria* sp. (both Noctuidae: Amphipyriinae). The possibility that they had not been recorded as new species previously, *Zale* nr. *obsita* and *Z.* nr. *sabina* (Erebidae: Catocolinae) were also collected. However, these may be found to belong to the nominal taxa after DNA barcoding. *Zale sabina* has a single Arizona record, while *Z. obsita* has been recorded in southern Texas. Voucher specimens were forwarded to Don Lafontaine, an Erebid/Noctuid expert at the Canadian National Collection (CNC) in Ottawa, Canada, for DNA barcoding and further analysis. A specimen of *Paraceliptera guerreronis* (Erebidae: Erebininae) and a specimen of the shiny white *Chasmina mexicana* (Noctuidae: Stiriinae) collected on the August trip also proved to be very significant records. Both of these moths were described earlier in the 1900s from much farther south (Guerrero state) by the German lepidopterist M. Draudt and figured in the famous German lithograph series on Lepidoptera by Seitz. The original type and

paratype specimens of these moths were destroyed in 1945 during WWII in the bombing of Dresden, Germany. The specimens collected at RG represent the first specimens collected since the type series and are currently with Don Lafontaine for DNA barcoding and study. These specimens will likely be designated neotypes of the two species. In addition to noctuids, two undescribed species of slug moths (Limacodidae) were collected at RG and specimens sent to specialist Marc Epstein in Sacramento, California. These specimens have been tentatively assigned to the genera *Natada* and *Miresa*.

Fall Sampling (September 3-5, 2011)

Conducted only a month after the initial sample, this trip yielded 214 identified taxa with almost half of these representing species not recorded in August. Virtually all of the “giant moths” seen a month earlier were absent as were most of the species with tropical affinities. Instead, there was an explosion of smaller moths, particularly those that feed on flowers. The noctuid family of Acontinae moths, better known as “bird dropping moths,” was particularly plentiful with 37 species in several closely related genera. Other noteworthy diversity was noted in the noctuid family Stiriinae, with 14 species records. Especially abundant was the bright orange “Goldenrod moth” *Cirrhophanus dyari*, with more than 100 showing up at the lights. A noctuid collected on this second trip was sent to Chris Schmidt in Canada, who recently revised the genus *Charadra* north of Mexico; He confirmed the moth as new — *C. nr. moneta*. An additional specimen of the rare *Chasmina mexicana* was recorded.

Larval activity was noteworthy in the fall sampling, and served as evidence that a flurry of moth activity had occurred with the onset of the monsoon rains. When known, these larvae were photographed and catalogued as records for MABA. Two particularly noteworthy species were *Crinotes beidermani* (Notodontidae), which had virtually denuded the *Ceonothus buxifolius* bushes around the compound, and *Eupackardia caletta* (Saturniidae) that was collected by a local cowboy on *Rhus aromatica*, a previously unrecorded foodplant for this moth.

Spring Sampling (April 1-3, 2011)

Despite cool evening temperatures and dry conditions, a spring sample at RG yielded an additional 122 taxa, 104 of these not being previously recorded. The Geometridae were especially diverse in this sample with 50 taxa collected including two possible new species. Several geometrids that are rarely encountered in the United States, and only in SE Arizona, were found to be common. *Stannodes apollo*, *Hydriomena mediodentata* and *Pityeja picta* were all abundant here. While the silkmoths (Saturniidae) are typically expected during the summer monsoon, a freshly emerged male *Copaxa lavendera* was an unusual and new record for RG. Like *C. multifenestrata*, the larvae of this moth are usually associated with plants in the Lauraceae. But, this widespread tropical species has also been reared in captivity on *Quercus*, a more likely host plant in this locality. The occurrence of this tropical species so early in the season indicates that winter temperatures must be comparatively mild at RG even though the resident vaqueros reported snow on the ground only a month before. Other interesting records include an unidentified white *Artace* spp (Lasiocampidae) and surprising spring broods (based on the numbers of individuals seen) of *Caripeta pulcherimma* and *Pityeja picta* (Geometridae), both of which occur as univoltine summer species in Arizona, *Pityeja* in the Chiricahuas only.

Discussion and Conclusions

The most surprising aspect of the RG locality has been the number of tropical taxa encountered much further north than previously known, especially given the lack of contiguous records between here and previously documented populations. Particularly striking examples of this are *Chasmina mexicana*, *Copaxa multifenestrata*, *Cropia europs*, *Metria sinaloa*, *Paraceliptera guerreronis* and *Phoenicoprocta lydia*. This likely is the result of sampling bias in the northern SMO, with more sampling historically occurring in the Alamos area. The tropical Sphingidae encountered are less surprising given their ability to feed and disperse across long distances as adults. *Copaxa lavendera* encountered in the spring sampling was also less surprising as it is rather well known in the Yécora area. Two saturniids previously known from Sonora only from the vicinity of Yécora, *Coloradia prchali* and *Copaxa muellerana*, represent significant range extensions for unusual SMO species. *Coloradia prchali* is an especially unique species, with males being the only members of the genus that are diurnal while the females only fly after dark. This species was only described in 1992 and it remains a near-endemic species for Sonora (with records from nearby Chihuahua) with a very limited range.

Ceiba acuminata is occasional in foothills thornscrub at lower elevations in the Sierra de Bacadéhuachi and must be the host plant of the *Dysdaemonia boreas* taken in early August. While seemingly out of place among the pines, Peter Hubbell reported that tropical moths often stray into the upland pine-oak forest in Guatemala (pers. comm. through T. Van Devender). As the adults of the Saturniidae do not feed, they have rather limited dispersal abilities. However, they do have significant fat energy reserves and they tend to fly up hill as do many Lepidoptera and other insects, so the specimen must have started life further down the slopes of the Sierra de Bacadéhuachi. The occurrence of this large tropical moth so far north is further evidence of the warmer temperatures in SMO versus northern pine-oak forests that allow 'tropical' plants to survive in close proximity to the oak/pine elevation. The *C. multifenestrata* record may also indicate a "pocket" of unsurveyed tropical vegetation near RG as this species is known to feed only of Lauraceae, a rather rare and restricted plant family in Sonora with no records of members being in the Sierra de Bacadéhuachi. As the related (but more widespread) *C. lavendera* feed on both Lauraceae and Fagaceae, it is possible that *C. multifenestrata* is utilizing a plant in another family, but the complete lack of records of the species between RG and Alamos remains confounding.

The connection between RG and the main Sierra Madre of Chihuahua was evident through several species more commonly encountered in Chihuahua than in Sonora. These include the two species of *Amastus* and the *Ammalo* nr. *paranomon* as well as *Copaxa lavendera*. The beetle *Chrysina adelaida* (Coleoptera; Scarabaeidae) recorded during both the summer and fall samplings at RG is a SMO species restricted in the Yécora area in Sonora and more commonly encountered in mountains of Chihuahua.

Unusually high numbers (hundreds of individuals) of the bright orange and black tiger moth *Epicrisias eschara* were encountered at RG in August. This moth does not occur in the United States and its life history (larva and foodplant) remains unknown. The moth was originally described from south of Mexico City (Dyar 1912) and was previously known to occur along the SMO axis as far north as Yécora. In 2010, two specimens, indicative of a small population, were documented in the Sky Island of Sierra La Madera and sampling

at RG indicates a robust population in the Sierra de Bacadéhuachi. It would be interesting to correlate the distribution of this moth with a particular host plant, and to see if the plant species also decreased in abundance between RG, Sierra La Madera, and Arizona.

The rediscovery of two taxa "lost" to science was exciting, especially given that the original types were described from Guerrero state nearly a century ago. This and the number of new taxa identified at RG are indicative of how incomplete our knowledge is of biodiversity in northern Mexico. New species recorded from RG include at least two members of the Erebididae and six members of the Noctuidae. All specimens of the Prominants (Notodontidae) were sent to Jim Miller, AMNH, New York, for review, and he tentatively believes at least four of these are undescribed, including a new *Disphragus* sp and *Psilacron* sp. Geometridae from the spring sampling are also likely to include two undescribed species in the genus *Hydriomena* (Geometridae: Laurentiinae), and the Limacodidae sample also included two undescribed taxa.

The intent of this initial survey of moths is to provide a starting point in the MABA database for future bioinventories of the Sierra de Bacadéhuachi and a comparison to other locations, particularly the Sky Island area to the north. SE Arizona's Sky Islands, while fairly well-inventoried for the last 100 years, still yield new species of moths every few years. The gap in our knowledge of species really lies to the south in the Sky Islands of Sonora and in the northern SMO proper. It is not at all surprising that more than a dozen species new to science have been identified from RG, given the paucity of sampling that has occurred in this area. It is a good reminder of the exciting biology and endemism that has developed in this region, where the new world tropics and the temperate zones meld together. As land use change in the northern sierra escalates to meet human needs, it becomes critically important that we know what is there so we can preserve some of it for the future. The relatively pristine state of RG compared with much of the heavily logged SMO makes it a standout for preservation from both natural history and human cultural history perspective.

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Sand Dune of Ruby, Arizona, an Anthropogenically Created Biodiversity Hotspot for Wasps and Their Velvet Ant Parasitoids

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Abstract—A large artificial sand dune composed of finely crushed mine tailings was produced by deep mining operations at Ruby, Arizona. Today, the ghost town of Ruby is an important historical location and biodiversity refuge, with the newly formed dune forming the core of the refuge. The dune provides ideal nesting habitat for at least 13 species of sand-loving wasps, including cicada killers (*Hymenoptera: Sphecidae*) that are sometimes present in record breaking populations. Following the colonizing wasps were at least 14 species of velvet ants (*Hymenoptera: Mutillidae*) that parasitize the wasps. Host wasp species range in size from about 9 to 1000 mg; various opportunistic velvet ant species exploit the entire host range of available wasps, resulting in velvet ants ranging in size from 6 to about 250 mg. These findings indicate that colonization of the man-made Ruby dune by both wasps and their parasitoids occurred rapidly after dune formation.

Introduction

Ruby was a prominent mining town in the Atascosa region of south-central Arizona near the border with Sonora. The town was named Ruby in 1912, not for the gemstone, but for Julius Andrews's wife, Ruby, who he certainly must have felt was a true gem (Weiser 2010). The town formed around vast, rich ore deposits that were mined on a small scale during the late 19th and early 20th Centuries. Starting in 1926 with the purchase of the mine by the Eagle-Picher Lead Company, the settlement became a boomtown through the 1930s, before closing in 1941. At its peak production in 1934-37, the mine was the largest producer in Arizona of lead and zinc and third largest in silver. Culturally, Ruby was a well operated company town reaching a population in its heyday of over 1200 inhabitants, and became best known for a pair of gruesome double murders in 1920-21 (Ring *et. al.* 2005; Weiser 2010).

A byproduct of the mine was a huge sand dune generated from the pulverized tailings of the mined ore. The sand tailings were dumped in the canyon next to the mine, eventually filling it to a height over 15 m and creating two lakes upstream. Although the exact date of the sand dune's creation is not clear, it undoubtedly began reaching its present size during the period of 1926-1940. Consequently, this man-made island of sand among the Sky Islands of the Madrean Archipelago is extremely recent in geologic terms. Currently the dune is home to a myriad of sand-loving wasps, mainly sphecid wasps (*Crabronidae* and *Sphecidae*) plus various paparazzi-like parasitic insects that follow their activities and exploit their nest and larval stores. The most abundant of these parasites are the velvet ants (family *Mutillidae*). Sphecid wasps, sometimes called hunting wasps, prey on various

insects and spiders, which they usually subdue via a paralyzing sting. In most cases the hapless inactivated prey is subsequently transported to a nest constructed by the wasp. Nests consist of several cells, each of which serves as the incubator for a wasp larva that feeds on the provisioned prey. When cells are completed with adequate food supplies, they are sealed and abandoned, leaving the larvae to develop on their own to form the next generation (O'Neill 2001).

Sphecid wasp nests are exploited by a variety of other wasps, flies, and others having a parasitic lifestyle. Aggregations of sphecid wasps, as in a limited sand dune area, present an abundance of resource opportunities, thereby often attracting large populations of many species of parasites. At Ruby, the most conspicuous of these parasites are the velvet ants. Not true ants, rather wasps with wingless ant-like females and winged males, velvet ants are among the hardest, most colorful, and best-defended insects known (Schmidt and Blum 1977). They are technically parasitoids because the larvae consume and kill the prey rather than just feeding, usually non-lethally, on a host as does a typical parasite. The hosts of many velvet ant species are unknown, in large part as a product of their lifestyles of entering the hidden cells of their hosts where they lay an egg on the quiescent host pupa or prepupa. Velvet ants frequently are considered opportunists that accept a wide variety of different species and sizes of hosts. Hosts are mainly bees and wasps (Brothers 1972).

The purpose of this investigation is to document the colonization of the Ruby sand dune by sand-loving wasps and their associated parasitic velvet ants.

Materials and Methods

All surveys were conducted exclusively on the Ruby dune proper from about mid-August through mid-September 2009-2011. The dune is located at 31° 27' 30.90" N, 111° 14' 00.04" W, elevation 1267 m. It measures approximately 334 x 143 m in length and width and has a total surface area of 4.00 x 10⁴ m² (4.00 hectares) (fig. 1). Within the dune are various areas including broad flat bare areas, small sparsely grassed stable hummocks elevated about a meter above the plain, larger eroding buttes 1-3 m in height, and deep eroding cliffs

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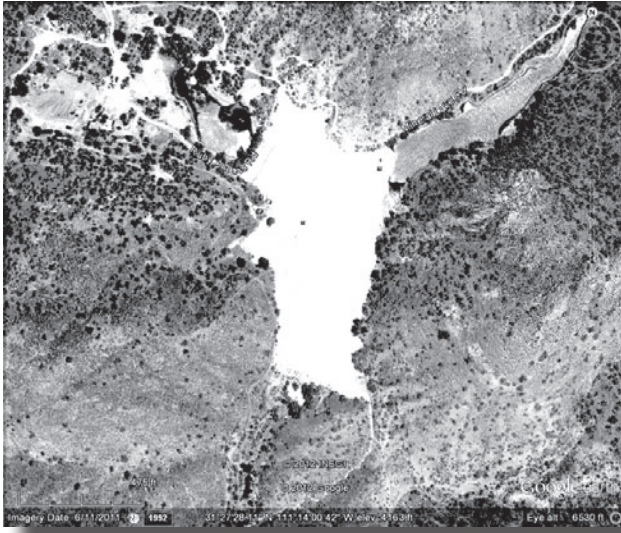


Figure 1—Google Earth image of Ruby dune and surrounding area.

where the dune meets the lower valley floor of the drainage basin. The sand throughout is very fine, uniform, and densely packed.

Wasps were collected manually and by insect net during daylight hours, placed on ice, and transported to the lab where their live weights and identities were determined. Voucher specimens are deposited in the University of Arizona Entomology Collection.

Results

Thirteen species of sand wasps were recorded on the dunes. Six of these were very common to abundant. The largest and most conspicuous sand wasp in Ruby, and perhaps of Arizona, is *Sphecius convalilis*, the Pacific cicada killer, so named because it paralyzes cicadas to provision its larvae. These huge bright yellow and light brown wasps attain lengths of 4 cm and weigh more than 1 g, with males usually much smaller than females (Coelho 1997). Ruby appears to have the largest population of these wasps known with well over a thousand individuals present during good years. Anybody visiting the dunes during their active period cannot avoid noticing these wasps,

especially the males actively patrolling territories and searching for females.

The second largest wasp on the dune is the “great black wasp”, *Sphex pennsylvanicus*, which weighs on average an estimated 300 mg and hunts katydids. This conspicuous species is common around the cliffs and buttes regions of the dune, though its numbers are considerably fewer than the cicada killers. *Ammophila* sp., a caterpillar hunter, weighs about 100 mg and can be observed resting on the sand or hovering just above it in many locations around the dune. Its slender shape, but not color pattern, makes this common wasp conspicuous. The large bembicine wasp, *Bicyrtes viduata*, actively flies and chases others in large aggregations in the flat areas near the dune center. This abundant and striking black and yellow wasp weighs on average 83 mg and paralyzes Hemiptera as prey. A smaller bembicine wasp, *Microbembix* sp., is even more abundant, perhaps being the most common species on the dune. This 26 mg wasp, resembling a small *Bicyrtes*, nests in the flat central dune area as well as other areas. It provisions its young with dead arthropods and fragments. A final abundant member of the big six common wasps is *Tachysphex* near *terminatus*. Unlike its larger wasp co-inhabitants, this tiny wasp, weighing only about 9 mg, is neither flashy, nor conspicuous. It is most prominently found around the hummock area of the dune where it provisions its nest with immature katydids and other orthopteran relatives.

In addition to the common dune wasps, are an assortment of infrequently encountered species. These species, usually observed singly or in low numbers, range in size from a large second species of *Bicyrtes* weighing about 150 mg to the 18 mg *Stenodynerus apache*. Five others species: *Cerceris* sp., *Eucerceris* sp., *Dolichodynerus vandykei*, *Podalonia sericea*, and an unidentified sphecid are present. Others undoubtedly also make the dune home.

A large, diverse guild of velvet ants shares the dune habitat with the sand wasps. These species range widely in size from the 6 mg *Dasymutilla monticola* to the nearly 250 mg *D. klugii* (*D. magnifica* is excluded, as only one specimen was found and the species is generally equal in size to *D. klugii*) (table 1). Twelve of the 14 species form a gradual size gradient from about 6 mg through 80 mg. The conspicuous outliers are the two ecological siblings, *D. klugii* and *D. magnifica*, which are about 3 times as large as the nearest sized species. In addition to filling all available size niches at the species level, the individual velvet ant species span enormous ranges in the size of individuals. For the most abundant species, those with three or four stars of relative abundance in table 1, the average size range

Table 1—Weights, size ranges, and relative abundances of velvet ants in the Ruby dune.

Velvet ant species	Weight (mg)	Weight range (n)	Size range (max wt/min wt) ^a	Relative Abundance
<i>Dasymutilla monticola</i>	5.9	2.9-12.7 (14)	4.38	***
<i>D. asteria</i> ♂♂	10.0	2.8-21.8 (23)	7.79	****
<i>D. asteria</i> ♀♀	11.7	3.8-21.9 (53)	8.82	****
<i>Pseudomethoca praeclara</i>	15.4	15.1-15.6 (2)		*
<i>P. contumex</i>	16	16 (1)		*
<i>D. dilucida</i>	20.1	7.8-46.5 (6)	5.96	**
<i>Timulla</i> near <i>dubitata</i>	22.8	22.8 (1)		*
<i>D. ferruginea</i>	~50	Estimate (1)		*
<i>D. chiron</i>	53.5	15.3-122.3 (81)	7.99	****
<i>D. eminentia</i>	63.0	34.6-91.7 (2)	2.64	**
<i>D. zelaya</i>	~63	Estimate (1)		*
<i>D. sicheliana</i>	64.5	31.5-83.0 (3)	2.68	**
<i>D. nogalensis</i>	78.4	45.8-109.5 (8)	2.39	***
<i>D. klugii</i>	239	123-400 (64)	3.25	****
<i>D. magnifica</i>	326	326 (1)		*

^aNo entry indicates insufficient data.



Figure 2—Size extremes in two velvet ant species, *Dasymutilla chiron* and *D. asteria*.

from smallest individual to largest individual is 5.26 (fig. 2). In comparison, the average size range within the most abundant sand wasps at Ruby is under 2.0 (data not shown). These numbers indicate that the sand wasps are more specialized, using a limited number of prey species, and that they additionally might have the opportunity to optimize the prey provisioned for each of their larvae. The wide size range for many velvet ant species reflects the fact that each velvet ant larva can only attain the size allowed by the available food in its cell; that is, the size of the host parasitized by its mother. If the mother's opportunities bring her to a host species with small individuals, the offspring will be small; if she finds host species have large individuals, the consequent velvet ant offspring will be large.

Discussion

The recent formation of the Ruby sand dune about 80 years ago provides an opportunity to investigate the speed of colonization of this new habitat. No other large man-made or natural sand dunes are present near Ruby and sand areas in the vicinity are scarce, small, and likely ephemeral areas along washes and stream courses. All wasps are partially limited by food resources (O'Neill 2001), but perhaps a more important factor for many species is availability of suitable nesting sites. If sand for nesting is scarce in the environment, that factor might be the crucial limitation in the life history of the species. The Ruby sand dune is unique in two ways: first, it is a huge sand resource for sand wasps; second, it is extremely recent in geologic time. The importance of the dune as a nesting resource is evident by the extreme population densities of wasps nesting in the dune and the large number of species present. The enormous numbers of cicada killers, a species rarely seen in other areas, is evidence that the environmental constraint on that species is not prey availability or prey carrying capacity, but, rather it is constraints on nesting locations. This flagship species provides a contrast to numerous other sand wasp species on the dune, many of which occur as in small numbers. The question arises, are these less common species limited by prey availability, some other factor, or were they constrained by ability to disperse to the dune from other areas? Are they recent arrivals that have not had adequate time to expand their populations? Long-term studies might well shed light on these questions.

Unlike the sand wasps, all of which can disperse by flight to arrive at Ruby, the velvet ant females are all flightless. That means to follow

their wasp hosts and to colonize the dune, they needed to crawl there. Given the potential distances involved and the sizes of the velvet ants, this seems a remarkable feat; especially given that at least 14 species have colonized the dune in less than 80 years. Collections of both sand wasps and velvet ants in the areas of Arizona and Sonora that surround Ruby have been sparse. We, therefore, have little knowledge concerning the distance the velvet ants might have been required to travel to get to Ruby, or the densities of individuals in the pools from which the immigrants came. In other locations around Arizona, velvet ants are infrequently encountered, an exception being in the stabilized dune area near Willcox, Arizona, that has as many or more species than Ruby (Justin Schmidt, personal observations). The Willcox area contrasts Ruby in that it is a much older sand formation and is surrounded by mainly flat surface terrain.

Specific hosts for velvet ants are infrequently known. One exception is the relationship between cicada killers and the two largest velvet ants at Ruby, *D. klugii* and *D. magnifica*. Both of these enormous velvet ant species require equally enormous hosts, and cicada killers fit the bill. Indeed, western cicada killers are recorded as the host for *D. klugii* (Bradley 1920). This restriction to one host species (perhaps, in exceptional cases, *Sphex pensylvanicus* can be an alternate host to produce small individuals) for *D. klugii* is reflected in the narrow size range from smallest to largest individuals of only 3.25. A similar prey limitation might also occur for *D. nogalensis*, the second largest species at Ruby, which also has the small size range in the order of 2.39 among individuals. In contrast to these large species, the small and medium sized velvet ant species exhibit huge size ranges up to an over 8-fold difference in size between smallest and largest individuals in a species. This suggests that these smaller species are not nearly as limited in their range of available hosts, and likely parasitize almost any available host on the dune within a wide size range.

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Bird List of San Bernardino Ranch in Agua Prieta, Sonora, Mexico

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Abstract—Interest and investigation of birds has been increasing over the last decades due to the loss of their habitats, and declination and fragmentation of their populations. San Bernardino Ranch is located in the desert grassland region of northeastern Sonora, México. Over the last decade, restoration efforts have tried to address the effects of long deteriorating economic activities, like agriculture and livestock, that used to take place there. The generation of annual lists of the wildlife (flora and fauna) will be important information as we monitor the progress of restoration of this area. As part of our professional training, during the summer and winter (2011-2012) a taxonomic list of bird species of the ranch was made. During this season, a total of 85 species and 65 genera, distributed over 30 families were found. We found that five species are on a risk category in NOM-059-ECOL-2010 and 76 species are included in the Red List of the International Union for Conservation of Nature (IUCN). It will be important to continue this type of study in places that are attempting restoration and conservation techniques. We have observed a huge change, because of restoration activities, in the lands in the San Bernardino Ranch.

Introduction

Birds represent one of the most remarkable elements of our environment, because they're easy to observe and it's possible to find them practically anywhere. Approximately 12% of all bird species in the planet are found in Mexico, this corresponds to 1060 species of a total of 8500 (INECOL 1996). This enormous diversity is due, among other reasons, to a bird species with Nearctic (North America) and Neotropical (Middle and South America) affinities; Mexico is the contact zone between these two biogeographic regions (INECOL, 1996).

Sonora varies seasonally from moist and cool to dry and hot. Here the northern fringe of the tropics meets the southern end of the temperature region, bringing plants and animals from both sources into a single state (Russell and Monson 1998). Due to this, Sonora has varied habitats like the deserts, grassy plains, and rugged mountains that may be arid and barren, or forest clad and split by great canyons. River valleys are bordered by gallery woodlands or by irrigated fields (Russell and Monson 1998). These characteristics produce a rich, diversified, and interesting biota, which still awaits full study.

According to the book *Diversidad Biológica de Sonora* (Molina-Freaner and Van Devender 2009), the birds of Sonora include 556 species in 73 families and 20 orders, with 227 resident species, 46 summer residents, 223 long distance migratory and 50 partially

migratory (Villaseñor-Gómez et al., 2010). Twenty-eight of those species are considered at risk on a global scale, and are included in the Red List of the International Union for Conservation of Nature (IUCN). Two-hundred-ninety are in the Neotropical Migratory Bird Conservation Act (NMBCA) of the United States and 66 species in the Mexican Official Norm NOM-059-ECOL-2001 (SEMARNAT 2010).

The length of the migration period may vary considerably among different species. Most of the Sonoran birds (41%) are year-round residents. Only 8.3% are summer residents that nest after returning from a winter stay to the South. Another group is composed of birds that breed in the United States and Canada, and then migrate south for varying distances to spend the colder months in Sonora or passing through to continue as far as southern South America (Russell and Monson 1998).

The study area is considered as the continuation of Arizona's Southeast birds and the extreme Southeast New Mexico's birds, bringing a mix of species with tropical and nearctic distributions, becoming an ecotone between the Chihuahuan and Sonoran Desert, and the Sierra Madre Occidental that divides both deserts (Molina-Freaner and VanDevender, 2009). This region is part of the Madrean Archipelago that constitutes mountain formations isolated by "oceans" of grass and deserted shrubs, acting like barrels or bridges that limit or make a possible genetic inter, (2011).

The area of San Bernardino has a history of agriculture and livestock exploitation beyond the recovery capacity of the land. In the last 20 years, restoration processes have been implemented with good results, making it necessary to intensify politics and economical resources to maintain and continue the ecological improvement (CEDES 2011).

Birds are very sensitive to environmental changes and, therefore, they can be used as indicators of environmental transformations, through changes in their distribution and temporal differences in their abundance (Hutto 1998). Research has increased in the last decades,

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due to the decline of many populations and fragmentation or loss of their habitats (Vickery et al., 1999). In recent years, vast areas have been cleared of all existing plant life and planted with African buffel grass (Poaceae: *Pennisetum ciliare*), creating a monoculture of little value to wildlife. Even more of Sonora is destined to be altered this way (Bowden 1993).

The objective of this work is to know the composition of bird species present in the San Bernardino Ranch, and contribute to the listing update of the wildlife of the area.

Area Description and Methods

The San Bernardino Ranch is located 31 kilometers from Agua Prieta-Janos road 31° 19' 0.20" N & 109° 15' 59.91" inside the State of Sonora. The observations occur on five different sites, locality one (L1) main house, locality two (L2) Silver Creek River, locality three (L3) San Bernardino River, locality four (L4) dam, locality five (L5) Cienega. The total area of observation was 3.9 km².

Three periods of observations were performed two times in daylight around 5 am to 11 am and from 5 pm to 7 pm. The first period was on July 4 to 10, 2011, called summer observation, and the other two periods were December 13 to 18, 2011, and March 14 to 18, 2012, being the winter observations. These dates were decided due to being part of our professional practices in our career as an obligatory process for our graduation.

Bird species were registered using direct observation by binoculars (10x42ALPEN and 12x42BUSHNELL) and the identification by field guides of birds such as Kaufman (2005), and Sibley (2000). There was no singing identification. A list of recorded species is presented as a main result of the study.

Results and Discussions

The total of species for all periods was of 85 species distributed in 30 families and 65 genus (table 1). On the summer observation (June) we observed a total of 46 species in 23 families and 42 genus. The winter observation's (December and March) results were of 63

Table 1—SBR total species of birds.

Order	Family <i>Scientific name</i>	Common name	Summer	Winter	NOM-059 -ECOL-2010 ^a	IUCN ^a
Accipitriformes	Accipitridae					
	<i>Accipiter cooperi</i>	Cooper's Hawk		x	Protección especial (PR)	
	<i>Buteo albonotatus</i>	Zone-tailed Hawk	x		Protección especial (PR)	
	<i>Buteo jamaicensis</i>	Red-tailed Hawk	x	x		Least Concern
	<i>Buteo regalis</i>	Ferruginous Hawk		x	Protección especial (PR)	Least Concern
	<i>Circus cyaneus</i>	Northern Harrier		x		Least Concern
	<i>Parabuteo unicinctus</i>	Harris's Hawk		x	Protección especial (PR)	Least Concern
	Cathartidae					
	<i>Cathartes aura</i>	Turkey Vulture	x	x		Least Concern
Anseriformes	Anatidae					
	<i>Anas strepera</i>	Gadwall		x		Least Concern
	<i>Aythya collaris</i>	Ring-necked Duck		x		Least Concern
	<i>Oxyura jamaicensis</i>	Ruddy Duck		x		Least Concern
Apodiformes	Apodidae					
	<i>Aeronautes saxatalis</i>	White-throated Swift		x		Least Concern
	Trochilidae					
	<i>Archilochus alexandri</i>	Black-chinned Hummingbird	x			Least Concern
	<i>Cynanthus latirostris</i>	Broad-billed Hummingbird	x	x		Least Concern
	<i>Selasphorus platycerus</i>	Broad-tailed Hummingbird	x			
Caprimulgiformes	Caprimulgidae					
	<i>Chordeiles acutipennis</i>	Lesser Nighthawk		x		Least Concern
	<i>Chordeiles minor</i>	Common Nighthawk	x	x		Least Concern
Charadriiformes	Charadriidae					
	<i>Charadrius vociferus</i>	Killdeer	x	x		Least Concern
	Scolopacidae					
	<i>Actitis macularius</i>	Spotted Sandpiper		x		Least Concern
Columbiformes	Columbidae					
	<i>Columbina inca</i>	Inca Dove	x	x		Least Concern
	<i>Streptopelia decaocto</i>	Eurasian Collared-Dove		x		Least Concern
	<i>Zenaida asiatica</i>	White-winged Dove	x	x		Least Concern
	<i>Zenaida macroura</i>	Mourning Dove	x	x		Least Concern
Cuculiformes	Cuculidae					
	<i>Geococcyx californianus</i>	Greater Roadrunner	x	x		Least Concern
Falconiformes	Falconidae					
	<i>Falco columbarius</i>	Merlin		x		Least Concern

Table 1—Continued.

Order	Family Scientific name	Common name	Summer	Winter	NOM-059 -ECOL-2010 ^a	IUCN ^a
Galliformes	Odontophoridae <i>Callipepla gambelii</i>	Gambel's Quail	x	x		Least Concern
Gruiformes	Rallidae <i>Fulica americana</i>	American Coot	x	x		Least Concern
Passeriformes	Bombycillidae <i>Bombycilla cedrorum</i>	Cedar waxwing		x		Least Concern
	Cardinalidae <i>Cardinalis cardinalis</i>	Northern Cardinal	x	x		Least Concern
	<i>Cardinalis sinuatus</i>	Pyrrhuloxia	x	x		Least Concern
	<i>Passerina caerulea</i>	Blue Grosbeak	x			Least Concern
	<i>Piranga rubra</i>	Summer Tanager		x		Least Concern
	Corvidae <i>Corvus corax</i>	Common Raven		x		Least Concern
	<i>Corvus cryptoleucus</i>	Chihuahuan Raven	x	x		Least Concern
	Emberizidae <i>Aimophila carpalis</i>	Rufous-winged Sparrow		x		
	<i>Aimophila ruficeps</i>	Rufous-crowned Sparrow		x		Least Concern
	<i>Amphispiza belli</i>	Sage Sparrow		x		Least Concern
	<i>Amphispiza bilineata</i>	Black-throated Sparrow	x	x		
	<i>Amphispiza quinquestriata</i>	Five-striped Sparrow		x		Least Concern
	<i>Chondestes grammacus</i>	Lark Sparrow		x		Least Concern
	<i>Melospiza melodia</i>	Song Sparrow		x		Least Concern
	<i>Passerculus sandwichensis</i>	Savannah Sparrow		x	Amenazada (A)	Least Concern
	<i>Pipilo chlorurus</i>	Green-tailed Towhee		x		Least Concern
	<i>Pipilo fuscus</i>	Canyon Towhee	x	x		Least Concern
	<i>Poecetes gramineus</i>	Vesper Sparrow	x	x		Least Concern
	<i>Spizella atrogularis</i>	Black-chinned Sparrow	x	x		Least Concern
	<i>Spizella passerina</i>	Chipping Sparrow		x		Least Concern
	<i>Zonotrichia leucophrys</i>	White-crowned Sparrow		x		Least Concern
	Fringillidae <i>Carduelis psaltria</i>	Lesser Goldfinch		x		Least Concern
	<i>Carpodacus mexicanus</i>	House Finch	x	x		Least Concern
	<i>Spinus tristis</i>	American Goldfinch	x			
	Hirundinidae <i>Hirundo rustica</i>	Barn Swallow	x			Least Concern
	<i>Tachycineta bicolor</i>	Tree Swallow		x		Least Concern
	Icteridae <i>Agelaius phoeniceus</i>	Red-winged Blackbird	x			Least Concern
	<i>Euphagus cyanocephalus</i>	Brewer's Blackbird		x		Least Concern
	<i>Molothrus ater</i>	Brown-headed Cowbird	x			
	<i>Molothrus aeneus</i>	Bronzed Cowbird	x			Least Concern
	<i>Quiscalus mexicanus</i>	Great-tailed Grackle	x			Least Concern
	Mimidae <i>Oreoscoptes montanus</i>	Sage Trasher		x		Least Concern
	Parulidae <i>Dendroica petechia</i>	Yellow Warbler	x			Least Concern
	<i>Geothlypis trichas</i>	Common Yellowthroat	x			Least Concern
	<i>Vermivora luciae</i>	Lucy's Warbler	x			
	<i>Vermivora ruficapilla</i>	Nashville Warbler	x			Least Concern
	Troglodytidae <i>Cistothorus palustris</i>	Marsh Wren		x		Least Concern
	<i>Thryomanes bewickii</i>	Bewick's Wren	x			Least Concern
	Turdidae <i>Turdus migratorius</i>	American Robin		x		Least Concern
	Tyrannidae <i>Contopus cooperi</i>	Olive-sided Flycatcher		x		Near Table

Table 1—Continued.

Order	Family Scientific name	Common name	Summer	Winter	NOM-059 -ECOL-2010 ^a	IUCN ^a	
Threatened	<i>Empidonax hammondii</i>	Hammond's Flycatcher		x		Least Concern	
	<i>Empidonax wrightii</i>	Gray Flycatcher		x		Least Concern	
	<i>Pyrocephalus rubinus</i>	Vermilion Flycatcher	x	x		Least Concern	
	<i>Sayornis nigricans</i>	Black Phoebe	x	x		Least Concern	
	<i>Sayornis phoebe</i>	Eastern Phoebe		x		Least Concern	
	<i>Sayornis saya</i>	Say's Phoebe	x	x		Least Concern	
	<i>Myiarchus cinerascens</i>	Ash-throated Flycatcher	x			Least Concern	
	<i>Tyrannus melancholicus</i>	Tropical Kingbird	x			Least Concern	
	Vireonidae						
		<i>Vireo gilvus</i>	Warbling Vireo	x			Least Concern
		<i>Vireo huttoni</i>	Hutton's Vireo		x		Least Concern
	Pelecaniformes	Ardeidae					
		<i>Ardea herodias</i>	Great Blue Heron	x			
		<i>Egretta caerulea</i>	Little Blue Heron	x	x		Least Concern
	Piciformes	Picidae					
	<i>Melanerpes formicivorus</i>	Acorn Woodpecker	x			Least Concern	
	<i>Melanerpes uropygialis</i>	Gila Woodpecker	x	x		Least Concern	
	<i>Picoides arizonae</i>	Arizona Woodpecker		x		Least Concern	
	<i>Picoides villosus</i>	Hairy Woodpecker		x		Least Concern	
	<i>Sphyrapicus nuchalis</i>	Red-naped Sapsucker		x		Least Concern	
Strigiformes	Strigidae						
	<i>Bubo virginianus</i>	Great Horned Owl	x	x		Least Concern	
	Tytonidae						
	<i>Tyto alba</i>	Barn Owl	x			Least Concern	
Total	30		46	63	5	76	
	85						

^aSpecies found in the NOM-059-ECOL-2010 and the International Union for Conservation of Nature are marked with the risk category under where they are established.

species in 28 families and 51 genus. In December we identified 35 species and in March 43 species were identified.

The 24 species that were in all observations were Black-throated sparrow (*Amphispiza bilineata*), Great Horned Owl (*Bubo virginianus*), Red-tailed Hawk (*Buteo jamaicensis*), Gambel's Quail (*Callipepla gambelii*), House Finch (*Capodarcus mexicanus*), Northern Cardinal (*Cardinalis cardinalis*), Pyrrhuloxia (*Cardinalis sinuatus*), Turkey Vulture (*Cathartes aura*), Killdeer (*Charadrius vociferus*), Common Nighthawk (*Chordeiles minor*), Inca Dove (*Columbina inca*), Chihuahuan Raven (*Corvus cryptoleucus*), Broad-billed Hummingbird (*Cyanthus latirostris*), Little Blue Heron (*Egretta caerulea*), American Coot (*Fulica americana*), Greater Roadrunner (*Geococcyx californianus*), Acorn Woodpecker (*Melanerpes uropygialis*), Canyon Towhee (*Pipilo fuscus*), Vesper Sparrow (*Pooecetes gramineus*), Vermilion Flycatcher (*Pyrocephalus rubinus*), Black Phoebe (*Sayornis nigricans*), Black-chinned Sparrow (*Spizella atrogularis*), White-winged Dove (*Zenaida asiatica*), Mourning Dove (*Zenaida macroura*).

We found that five species are on a risk category in NOM-059-ECOL-2010, four are in Special Protection (Pr): Cooper's Hawk (*Accipiter cooperi*), Zone-tailed Hawk (*Buteo albonotatus*), Red-tailed Hawk (*Buteo jamaicensis*), Ferruginous Hawk (*Buteo regalis*), Harris's Hawk (*Parabuteo unicinctus*); one is threatened (A): Savannah Sparrow (*Passerculus sandwichensis*); and none is endemic of Mexico; 76 species are included in the Red List of the International Union for Conservation of Nature (IUCN) as least concern "LC" and one species is near threatened "NT" (Olive-sided Flycatcher). This is important

because the risk species help to declare protected areas, ensuring the preservation of the rich flora, fauna, and environmental services.

In August and October of 2005, Rob Hunt made a report of bird observations in the San Bernardino Ranch, and found 61 species of birds. We found 31 of those observed; we didn't know exactly the area where the observations took place, so we can't compare the total or both results (Cuenca Los Ojos 2012).

The San Bernardino National Wildlife Refuge (SBNWR) located in the border east of Douglas Arizona, next to the San Bernardino Ranch, has 30 years of protecting water resources and habitats. They have registered over 270 species of birds; if we consider those data as 100% of the bird species present in SBNWR, we can say that we have observed 31.48% of species. Also, the SBNWR has an area of 9.34 km² and our area of observations was made on 3.9 km² (U.S. Fish & Wildlife Service 2011).

Conclusions

It is important to keep having this type of study in places that are actively implementing restoration and conservation techniques. We have seen a huge change in the lands in the San Bernardino Ranch; there is more retained soil and water, which attracts many diverse species. Also, we didn't find considerable threatened species in the Red List of IUCN and NOM-059-ECOL-2010, but we are aware that actions of conservation and restoration in the future will bring a healthy habitat that would help in the improvement and development of the ecological interactions.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Preliminary Assessment of Species Richness and Avian Community Dynamics in the Madrean Sky Islands, Arizona

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Abstract—The Sky Island mountain ranges of southeastern Arizona contain a unique and rich avifaunal community, including many Neotropical migratory species whose northern breeding range extends to these mountains along with many species typical of similar habitats throughout western North America. Understanding ecological factors that influence species richness and biological diversity of both resident and migratory species is important for conservation of this unique bird assemblage. We used a 5-year data set to evaluate avian species distribution across montane habitat types within the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleno Mountains. Using point-count data from spring-summer breeding seasons, we describe avian diversity and community dynamics. We use a Bayesian hierarchical model to describe occupancy as a function of vegetative cover type and mountain range latitude, and detection probability as a function of species heterogeneity and sampling effort. By identifying important habitat correlates for avian species, these results can help guide management decisions to minimize loss of key habitats and guide restoration efforts in response to disturbance events in the Madrean Archipelago.

Introduction

The Sky Island mountain ranges of southeastern Arizona, USA, contain a unique and rich avifaunal community. Habitat diversity from mixing of Madrean and Cordilleran flora supports many species, including Neotropical migratory species whose northern breeding ranges extend to these mountains, and species typical of similar habitats throughout western North America. Many species of concern from the National Audubon Society/American Bird Conservancy Watchlist (2007) and U.S. Fish and Wildlife Service (2008) Birds of Conservation Concern (<http://www.fws.gov/birdhabitat/Grants/NMBCA/BirdList.shtm>) occur within this area. The Mexican Highlands Partners In Flight (PIF) Physiographic Area Plan (http://www.blm.gov/wildlife/pl_81sum.htm, Sonoran Joint Venture Technical Committee 2006) and Arizona PIF plan (Latta and others 1999) indicate conservation issues of water use, urban development, overgrazing, and recreation. Understanding ecological factors that influence species richness of both resident and migratory species is important for conservation of this unique bird assemblage, yet few studies describe bird habitat requirements in the Sky Islands (e.g., Balda 1967; Block and others 1992; Block and Severson 1992; Hall and Mannan 1999; Marshall 1957). Past studies indicate riparian areas support the most bird species (Balda 1967; Strong and Bock 1990), but upland habitats also contribute to species diversity (Marshall 1957).

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We studied occupancy and cover type associations of forest birds across montane vegetative cover types in the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleno Mountains of southeastern Arizona from 1991 to 1995 (Block and others 1992; Block and Severson 1992). We used occupancy models (MacKenzie and others 2006) to estimate species richness and community dynamics (local species extinction, local species colonization), while accounting for detection (e.g., Dorazio and others 2006). Imperfect detection of species is important to include in analyses, especially with rare or elusive species, or when trying to assess change over time. Estimates of species richness and community dynamics could be biased if species occupy an area but were never detected during a survey or multiple surveys. This could lead to biased study conclusions used to guide management actions. Our objectives were to (1) estimate species richness across mountain range and cover type; (2) relate species occurrence to forest cover types within these ranges; and (3) estimate probability of local species extinction and colonization.

Methods

Study Area

Our study area (elevation: 1,470–3,000 m) consisted of woodlands, pine-oak forests (*Pinus* spp. – *Quercus* spp.), pine forests, and mixed-conifer forests within the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleno Mountains, of the Coronado National Forest and Fort Huachuca (Department of Defense) in southeastern Arizona, USA (fig. 1). Major tree species included Arizona white (*Q. arizonica*), silverleaf (*Q. hypoleucoides*), Emory (*Q. emoryi*), Gambel (*Q. gambeli*), and netleaf (*Q. reticulata*) oaks; ponderosa (*P. ponderosa*), Apache (*P. engelmanni*), Chihuahuan (*P. leiophylla*), Mexican white (*P. strobiformis*), and border pinyon (*P. discolor*)

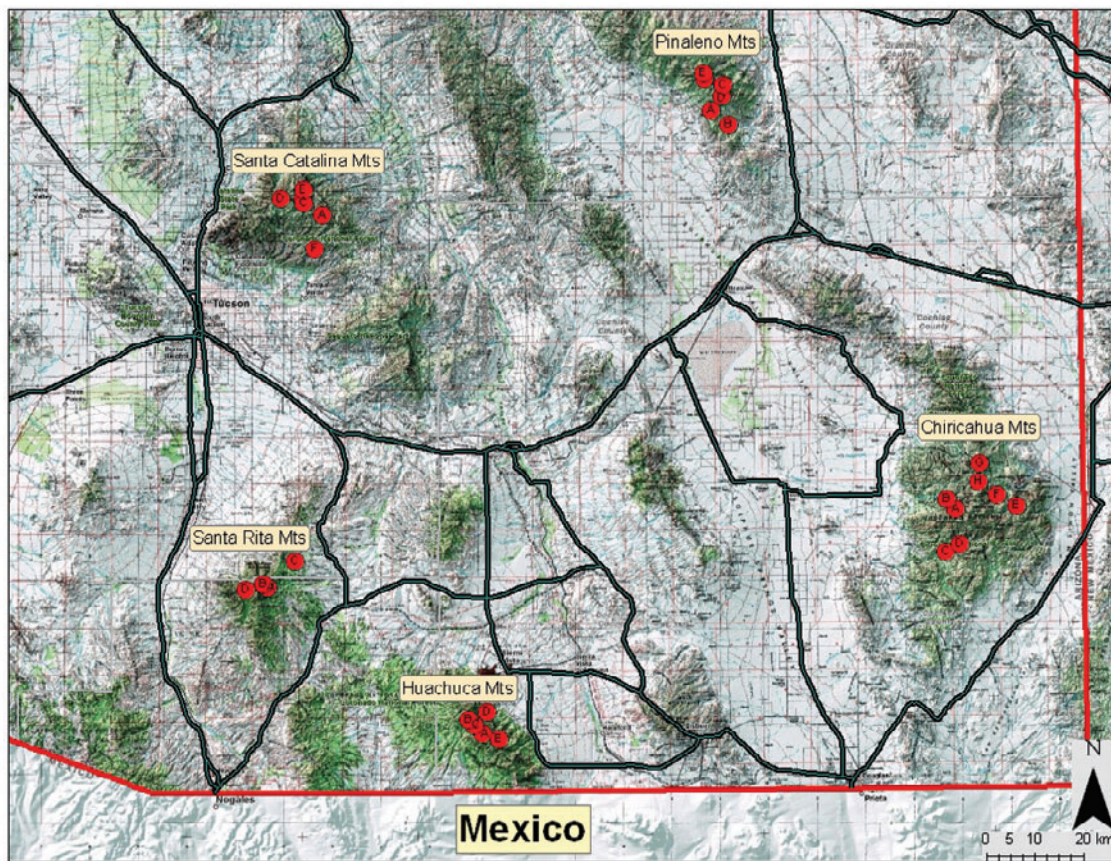


Figure 1—Study area from the Sky Island mountain ranges of Santa Catalina, Piñaleno, Santa Rita, Huachuca, and Chiricahua mountains of southeastern Arizona, USA from 1991 to 1995. Labeled dots within the mountain ranges indicate transect locations for avian point counts.

pinus; alligator-bark juniper (*Juniperus deppeana*); white fir (*Abies concolor*); and Douglas-fir (*Pseudotsuga menziesii*) (Iniguez and others 2005).

Field Sampling

Count points ($n = 344$) were located along transects consisting of 12 points spaced at 300 m intervals, with the exception of one transect that had only 8 points. Transects ($n = 29$) were established using a systematic-random sampling design (Cochran 1977), and occurred in proportion to occurrence of vegetation types in the landscape. Using the variable-radius point count method (Reynolds and others 1980), we sampled birds at each point three times during each breeding season (Apr-July) from 1991 to 1995. Counts (5 min/point) began within 30 min of sunrise and completed no later than 4 hr after sunrise. Observers remained still for 1-2 min after reaching a point, then recorded species, age, and sex of birds detected.

We sampled diameter at breast height (DBH) of all trees and snags in four 0.1-ha circular plots located within 100 m of each point count station. We used these data to estimate a weighted percent basal area average (WBA) of live and dead trees for each point count plot. We used cluster analysis with WBA (Iniguez and others 2005) to classify plots into 7 broad vegetative types for covariates in our occupancy models: deciduous forest, mixed-conifer forest, pine-oak forest, broadleaf evergreen woodland, conifer woodland, conifer riparian, and ponderosa pine.

Analytical Analyses

Our sampling design was a robust design (Pollock 1982), in which sampling occurred on up to three secondary periods (visits) during each primary period (years). Occupancy states of species can change with local extinction and colonization between primary periods, but not during secondary periods. We condensed data across points within each mountain \times cover type combination to increase species detections per combination and reduce model complexity. Using these occupancy states with latent variable z_{ihmt} for occupancy of species i , cover type h , mountain m at time t , we calculated derived parameters, including species richness (N), species colonization (γ) and species extinction (ϵ). We calculated the average number of species in each mountain range and cover type over all 5 years:

$$N_{hm} = \frac{\sum_{t=1}^5 \sum_{i=1}^M z_{ihmt}}{5}$$

We also calculated the average over all 5 years for local species colonization (γ), probability that a species selected at random from the community was not present in the community at time $t-1$, and local species extinction (ϵ), or probability that a species selected at random from the community was present at time $t-1$ but not at time t (Williams and others 2002):

$$\gamma(mh) = \frac{\sum_{t=1}^5 \left[\frac{\sum_{i=1}^M (z_{imht}) \times (1 - z_{imh,t-1})}{\sum_{i=1}^M z_{imh,t-1}} \right]}{5}$$

$$\varepsilon(mh) = \frac{\sum_{t=1}^5 \left[\frac{\sum_{i=1}^M (1 - z_{imht}) \times (z_{imh,t-1})}{\sum_{i=1}^M z_{imh,t-1}} \right]}{5}$$

We used a data matrix y , where element y_{imht} was a binary indicator of species detection. When $y_{imht} = 1$, species i ($i = 1, \dots, N$) was detected in mountain range m ($m = 1, \dots, 5$) in cover type h ($h = 1, \dots, 7$) of year t ($t = 1, \dots, 5$). We used the sum of binary species detection indicators for each species \times mountain range \times cover type \times year combination over all three secondary periods during that combination ($y_{imht} = \{0, 1, 2, 3\}$). We used species and effort (eff) to model species detection and expected detection probability to increase with effort and to vary among species. We used latitude (lat) and cover type (hab) to model probability of occupancy of species. Since we condensed points by cover type and mountain range, we were unable to use elevation as an explanatory variable; however, there is a weak relationship between cover type and elevation (table 1). We expected that species occupancy patterns would vary among cover types, and species richness would decrease with increasing latitude due to loss of species with Mexican and Central American distributions. For numerical reasons, we used normalized covariates for effort and latitude. We defined effort as

number of points in each mountain range \times cover type combination (table 1). Each sampling unit ($n = 35$) consists of points classified by cover type within each mountain range. We used the mean latitude from UTM coordinates of each mountain range as a covariate (Chiricahuas = 3533798, Huachucas = 3474145, Pinalaños = 3618746, Santa Catalinas = 3589560, Santa Ritas = 3509745).

Since we were interested in the whole avian community, quantification of both observed species and species we did not detect, but may have been present, were of interest. Bayesian hierarchical models with unknown species richness (Royle and Dorazio 2008: 384-387) that rely on data augmentation (e.g., Dorazio and others 2006) allow us to make inference on the entire community. We used a fixed supercommunity size M , so the posterior distribution of Ω , probability a species from the supercommunity was available for sampling during primary sampling periods, was centered well below its upper limit (e.g., $\Omega \leq 0.5$). We augmented the species observation matrix y with $(M - n_{obs})$ rows of zeros for all mountain range \times cover type \times primary period sampling sessions. We modeled probability of latent variable w_i of species i being available for sampling during all primary sampling periods given Ω as a Bernoulli trial:

$$[w_i | \Omega] \sim \text{Bern}(\Omega).$$

To model community change, we assumed a Markovian process described the current occupancy state of each species, whereby probability of occupancy at time t was partially dependent on probability of occupancy at time $t-1$. We modeled probability of Bernoulli latent variable z_{imht} for occupancy given probability of occupancy ψ_{imht} and w_i as:

$$[z_{imht} | \psi_{imht}, w_i] \sim \text{Bern}(\psi_{imht} \times w_i),$$

where occupancy probability ψ_{imht} is a function of covariates and the previous occupancy state:

Table 1—Number of avian sample points and elevation range across seven cover types within five mountain ranges in the Sky Islands, Arizona, USA 1991-1995. Normalized values of sampling effort were used as a covariate for estimating detection probability in our Bayesian hierarchical model. Elevation ranges (m) for each mountain range \times cover type combination are indicated within parentheses below the number of sample points.

Mountain Range	Forest and woodland habitat types						
	Deciduous forest	Mixed-conifer forest	Pine-oak forest	Broadleaf evergreen woodland	Conifer woodland	Conifer Riparian	Ponderosa pine
Chiricahua	1 (2340)	12 (2207-2621)	24 (1780-2304)	17 (1692-2280)	25 (1591-2377)	4 (1890-2012)	9 (2283-2530)
Huachuca	1 (2446)	9 (2012-2438)	9 (1964-2278)	17 (1585-2134)	23 (1626-2568)	0	1 (2301)
Pinalaño	4 (1951-2749)	28 (2012-2926)	4 (2195-2414)	13 (1500-2118)	11 (1469-1987)	0	12 (2048-2554)
Santa Catalina	1 (2091)	25 (1957-2707)	11 (2018-2475)	13 (1487-2088)	6 (1561-1905)	0	16 (2048-2487)
Santa Rita	0 -	6 (2262-2396)	6 (1768-2219)	29 (1667-2341)	7 (1707-2274)	0	0 -

$$\text{logit}(\psi_{ihmt}) = \begin{cases} a_{i0} + a_{i1(0)} \times z_{ihm0} + a_{i2} \times \text{lat}_m + a_{i3h}, & t = 1 \\ a_{i0} + a_{i1} \times z_{ihm,t-1} + a_{i2} \times \text{lat}_m + a_{i3h}, & t > 1. \end{cases}$$

Values $a_{i1(0)}$ and a_{i1} describe local probability of survival for species i . These terms describe species-specific normal random effects: a_{i0} (intercept), a_{i3h} (cover type), and a_{i2} (latitude).

We modeled probability of observation of species i , y_{ihmt} , given the number of secondary periods J , probability of detection p_{ihm} and latent variable z_{ihmt} , using a binomial distribution with J trials and probability of success $p_{ihm} \times z_{ihmt}$:

$$[y_{ihmt} | J, p_{ihm}, z_{ihmt}] \sim \text{Bin}(J, p_{ihm} \times z_{ihmt}).$$

We used species and sampling effort (eff) as covariates to model probability of detection p :

$$\text{logit}(p_{ihm}) = b_{i0} + b_1 \times eff_{hm}.$$

We modeled heterogeneity among species using a covariance term between species intercepts of occurrence (a_{i0}) and detection probability (b_{i0}) (Royle and Dorazio 2008: p. 391), which allows us to make inference on occupancy and detection probability of species we never detected.

We used Bayesian hierarchical models (Gelman and others 2004) in R2WinBUGS (Sturtz and others 2005), an R (R Development Core Team 2011) package that interfaces with WinBUGS (Lunn and others 2000) to obtain parameter estimates. We used independent non-informative priors for parameters (uniform: $\Omega, a_{i1(0)}$; Bernoulli: z_{ihm0} ; Normal: $a_{i0}, a_{i1}, a_{i2}, a_{i3h}, b_{i0}, b_1$; e.g., $b_{i0} \sim N(\mu_{b_0}, \sigma_{b_0}^2)$). We ran four parallel chains (length 35,000 it , burn-in period 20,000 it , thinning 10 it) to obtain median parameter estimates and 95% Bayesian Credible Intervals (BCI). Convergence was reached ($\hat{R} = 1.0$ -1.1 [Brooks and Gelman 1998]). We assessed goodness-of-fit (GOF) using the squared loss and deviance test statistics for Bayesian p -values (Gelman and others 2004: p. 162).

Results

Over all mountain ranges, cover types, and years, we detected 158 bird species (table 2). Number of species observed (n_{obs}) was comparable ($n_{obs,1991} = 119, n_{obs,1992} = 117, n_{obs,1993} = 107, n_{obs,1994} = 120, n_{obs,1995} = 110$) across years. There was evidence of overdispersion (Bayesian p -value squared loss = 1.0, Bayesian p -value deviance = 0.66). The probability of a species being a supercommunity member (median $\Omega = 0.506$, 95% BCI: 0.408-0.68) indicates that our data augmentation step was appropriate. Detection probabilities varied by species (logit scale hyperprior medians: $\hat{\mu}_{b_0} = 0.078, \hat{\sigma}_{b_0}^2 = 0.797$)

and increased with increased sampling effort (median $\hat{b}_1 = 0.671$, 95% BCI: 0.627-0.714).

Average species richness was different for each mountain range and cover type, although 95% BCIs overlapped (fig. 2). For all mountain ranges, species richness was greatest in broadleaf evergreen woodland and conifer woodland cover types and least in deciduous forest. Species richness decreased as latitude increased in mixed-conifer, pine-oak woodland, broadleaf evergreen woodland and conifer riparian cover types. Deciduous forest, conifer woodland, and ponderosa pine cover types had no association with species richness and latitude. Average local extinction and colonization were similar for all cover types and mountain ranges (fig. 3), except for Pinaleno Mountain ponderosa pine ($\hat{\mathcal{E}} : 0.205 [0.156, 0.256]; \hat{\mathcal{Y}} : 0.383 [0.282, 0.549]$). Species turnover, or the process of local extinction and replacement of species

through local colonization, was greatest within deciduous forest for most mountain ranges and smallest within pine-oak forest, broadleaf evergreen woodland, and conifer woodland cover types.

Fourteen species had positive slopes with latitude and 18 species had negative slopes associated with latitude (95% BCIs for these species did not cross zero; fig. 4). Some species had positive median cover type slopes, although the 95% BCIs overlapped zero, for deciduous forest ($n = 3$), mixed-conifer forest ($n = 35$), pine-oak forest ($n = 25$), broadleaf evergreen woodland ($n = 57$), conifer woodland ($n = 64$), conifer riparian ($n = 6$) and ponderosa pine ($n = 17$) (table 2).

Discussion

We identified associations between forest cover type and avian species: broadleaf evergreen woodland and conifer woodland contributed the most species. Deciduous forest cover type, which occurred at higher elevations in these mountain ranges, had the greatest species turnover, but fewest species. As expected, species richness increased with decreased latitudes in four of the seven cover types. Many species that occur in southerly latitudes have Mexican and Central American distributions (e.g., elegant trogon, eared trogon, thick-billed parrot [scientific names given in table 2]). Southernmost Arizona mountain ranges encompass the northern part of these species ranges. These relationships in mixed-conifer, pine-oak woodland, broadleaf evergreen woodland and conifer riparian cover types may have implications for avian range shifts with climate change. Most climate models predict warmer and drier future conditions in the southwestern United States (Seager and others 2007), thus species whose ranges are more southern may move northward with warming climates, particularly if changes create expanded habitat availabilities. Lower elevation cover types may shift upwards and higher elevation cover types may shrink or disappear, leading to decline or loss of species with strong habitat associations.

Our results suggest not all species present were detected during sampling and detection probability increased with increased sampling effort. This highlights the importance of sample design and accounting for detection probabilities within occupancy models (MacKenzie and others 2006). Detection probabilities are critical in studies that assess changes over time or responses to disturbance events, because detection probability may change over time or with habitat changes. Several species in our study had low detectability, which is known to cause bias in occupancy estimates (MacKenzie and others 2006: p. 107) and can lead to inflated estimates of species richness.

Our preliminary analyses suggest that cover type may not be the best explanatory variable for the probability of occupancy due to some evidence of overdispersion. Other factors like elevation, microhabitat structure, slope and aspect, mountain range area, and distance to other mountains may have more explanatory power, which warrants future exploration. Future analyses will focus on estimating relative abundances (sensu Royle and Nichols 2003), detailed habitat relationships of individual avian species, especially species of conservation concern, and evaluation of resident and migratory species for their relative contributions to species richness and community dynamics. This information will be valuable to managers charged with conserving this unique avifauna, and aid in assessing potential impacts of changing climates.

Our study also provides a baseline for future studies in this Global Important Bird Area (Audubon Society). The Sky Islands have been impacted by several large-scale, habitat altering disturbance events in recent years (e.g., the 2011 Horseshoe Two fire burned 90,307 ha

within the Chiricahua Mountains) and these large-scale disturbance events may become more frequent as climate in the southwestern United States becomes warmer and drier (McKenzie and others 2004). Consequent changes in habitat structure could influence avian

community dynamics in these ranges. We know little about effects of fire and other disturbances on Neotropical migratory birds in this region (Ganey and others 1996; Kirkpatrick and others 2006), thus, future monitoring aimed at evaluating effects of fire events and climate shifts on avian species in the region are paramount.

Table 2—Avian species with positive posterior medians associated with cover types within the five Sky Island mountain ranges in southeastern Arizona, USA from 1991 to 1995. The number '1' indicates a positive posterior median for the specific habitat type. Some species did not have any positive associations and some species were associated with more than one cover type.

Common species name	Scientific name	Cover types						
		Dec. for.	Mix.- conf. for.	Pine- oak for.	Brd. Evgr. wd.	Conf. wd.	Conf. ripa.	Pond. pine
Mallard	<i>Anas platyrhynchos</i>	0	0	0	0	1	0	0
Gambel's quail	<i>Callipepla gambelii</i>	0	0	0	1	1	0	0
Scaled quail	<i>Callipepla squamata</i>	0	0	0	0	0	0	0
Montezuma quail	<i>Cyrtonyx montezumae</i>	0	0	0	1	1	0	0
Wild turkey	<i>Meleagris gallopavo</i>	0	0	0	0	0	0	0
Turkey vulture	<i>Cathartes aura</i>	0	0	0	1	1	0	0
Cooper's hawk	<i>Accipiter cooperii</i>	0	0	0	0	0	0	0
Northern goshawk	<i>Accipiter gentilis</i>	0	1	0	0	0	0	1
Sharp-shinned hawk	<i>Accipiter striatus</i>	0	0	0	0	1	0	0
Gray hawk	<i>Buteo nitidus</i>	0	0	0	0	0	0	0
Zone-tailed hawk	<i>Buteo albonotatus</i>	0	0	0	0	0	0	1
Red-tailed hawk	<i>Buteo jamaicensis</i>	0	0	0	1	0	0	0
Common black-hawk	<i>Buteogallus anthracinus</i>	0	0	0	0	0	0	1
Golden eagle	<i>Aquila chrysaetos</i>	0	0	0	0	0	0	0
Prairie falcon	<i>Falco mexicanus</i>	0	0	0	0	1	0	0
American kestrel	<i>Falco sparverius</i>	0	0	0	0	0	0	0
Band-tailed pigeon	<i>Patagioenas fasciata</i>	0	0	1	0	0	0	0
Rock dove	<i>Columba livia</i>	0	0	0	0	0	0	1
White-winged dove	<i>Zenaida asiatica</i>	0	0	0	1	1	0	0
Mourning dove	<i>Zenaida macroura</i>	0	0	0	1	1	0	0
Thick-billed parrot	<i>Rhynchopsitta pachyrhyncha</i>	0	1	0	0	0	0	0
Greater roadrunner	<i>Geococcyx californianus</i>	0	0	0	1	1	0	0
Great horned owl	<i>Bubo virginianus</i>	0	0	0	0	0	0	0
Northern pygmy-owl	<i>Glaucidium gnoma</i>	0	0	1	0	0	0	0
Flammulated owl	<i>Otus flammeolus</i>	0	1	0	0	0	0	0
Whiskered screech-owl	<i>Megascops trichopsis</i>	0	0	1	0	0	0	0
Spotted owl	<i>Strix occidentalis</i>	0	1	0	0	0	0	0
Lesser nighthawk	<i>Chordeiles acutipennis</i>	0	0	0	0	1	0	0
Eastern whip-poor-will	<i>Caprimulgus vociferus</i>	0	0	0	1	0	0	1
White-throated swift	<i>Aeronautes saxatalis</i>	0	1	0	0	0	1	0
Black-chinned hummingbird	<i>Archilochus alexandri</i>	0	0	1	1	1	0	0
Anna's hummingbird	<i>Calypte anna</i>	0	0	0	1	0	0	0
Costa's hummingbird	<i>Calypte costae</i>	0	0	0	0	0	0	0
Broad-billed hummingbird	<i>Cynanthus latirostris</i>	0	0	0	0	1	1	0
Magnificent hummingbird	<i>Eugenes fulgens</i>	0	1	0	0	0	0	0

(continued)

Table 2—Continued

Common species name	Scientific name	Dec. for.	Mix.-conf. for.	Pine-oak for.	Brd. Evgr. wd.	Conf. wd.	Conf. ripa.	Pond. pine
Blue-throated hummingbird	<i>Lampornis clemenciae</i>	0	0	0	0	0	1	0
Broad-tailed hummingbird	<i>Selasphorus platycercus</i>	0	1	0	0	0	0	0
Rufous hummingbird	<i>Selasphorus rufus</i>	0	0	0	0	0	0	0
Eared quetzal	<i>Euptilotis neoxenus</i>	0	0	0	0	0	0	0
Elegant trogon	<i>Trogon elegans</i>	0	0	1	0	0	1	0
Northern flicker	<i>Colaptes auratus</i>	0	0	0	0	0	0	0
Acorn woodpecker	<i>Melanerpes formicivorus</i>	0	0	1	1	1	0	0
Gila woodpecker	<i>Melanerpes uropygialis</i>	0	0	0	1	0	0	0
Ladder-backed woodpecker	<i>Picoides scalaris</i>	0	0	0	1	1	0	0
Strickland's woodpecker	<i>Picoides stricklandii</i>	0	0	0	1	1	0	0
Hairy woodpecker	<i>Picoides villosus</i>	0	1	1	0	0	0	1
Red-naped sapsucker	<i>Sphyrapicus nuchalis</i>	0	1	0	0	0	0	0
Northern beardless-tyrannulet	<i>Camptostoma imberbe</i>	0	0	0	1	1	0	0
Black phoebe	<i>Sayornis nigricans</i>	0	0	0	0	1	0	0
Say's phoebe	<i>Sayornis saya</i>	0	0	0	1	0	0	0
Olive-sided flycatcher	<i>Contopus cooperi</i>	0	0	0	0	0	0	0
Greater pewee	<i>Contopus pertinax</i>	0	1	1	0	0	0	1
Western wood-pewee	<i>Contopus sordidulus</i>	0	0	1	0	0	0	0
Pacific-slope flycatcher	<i>Empidonax difficilis</i>	0	1	0	0	0	0	0
Buff-breasted flycatcher	<i>Empidonax fulvifrons</i>	0	1	0	0	0	0	0
Hammond's flycatcher	<i>Empidonax hammondii</i>	0	1	0	0	0	0	0
Dusky flycatcher	<i>Empidonax oberholseri</i>	0	0	0	0	1	0	0
Cordilleran flycatcher	<i>Empidonax occidentalis</i>	0	1	0	0	0	0	0
Gray flycatcher	<i>Empidonax wrightii</i>	0	0	0	1	0	0	0
Dusky-capped flycatcher	<i>Myiarchus tuberculifer</i>	0	0	0	0	1	0	0
Ash-throated flycatcher	<i>Myiarchus cinerascens</i>	0	0	0	1	1	0	0
Brown-crested flycatcher	<i>Myiarchus tyrannulus</i>	0	0	0	0	1	0	0
Sulphur-bellied flycatcher	<i>Myiodynastes luteiventris</i>	0	0	1	0	0	0	0
Thick-billed kingbird	<i>Tyrannus crassirostris</i>	0	0	0	0	1	0	0
Western kingbird	<i>Tyrannus verticalis</i>	0	0	0	0	0	0	0
Cassin's kingbird	<i>Tyrannus vociferans</i>	0	0	0	1	1	0	0
Rose-throated becard	<i>Pachyramphus aglaiae</i>	0	0	0	1	0	0	0
Loggerhead shrike	<i>Lanius ludovicianus</i>	0	0	0	1	0	0	0
Bell's vireo	<i>Vireo bellii</i>	0	0	0	0	1	0	0
Warbling vireo	<i>Vireo gilvus</i>	0	1	1	0	0	0	0
Hutton's vireo	<i>Vireo huttoni</i>	0	0	1	1	0	0	0
Plumbeous vireo	<i>Vireo plumbeus</i>	0	0	1	0	0	0	0
Gray vireo	<i>Vireo vicinior</i>	0	0	0	0	1	0	0
Western scrub-jay	<i>Aphelocoma californica</i>	0	0	0	1	1	0	0
Stellar's jay	<i>Cyanocitta stelleri</i>	0	0	1	0	0	0	0
Gray jay	<i>Perisoreus canadensis</i>	0	0	1	1	1	0	0
Common raven	<i>Corvus corax</i>	0	0	0	1	0	0	0
Chihuahan raven	<i>Corvus cryptoleucus</i>	0	0	0	0	0	0	0
Tree swallow	<i>Tachycineta bicolor</i>	0	1	0	0	0	0	0

(continued)

Table 2—Continued

Common species name	Scientific name	Dec. for.	Mix.- conf. for.	Pine- oak for.	Brd. Evgr. wd.	Conf. wd.	Conf. ripa.	Pond. pine
Violet-green swallow	<i>Tachycineta thalassina</i>	0	1	0	0	0	0	0
Mountain chickadee	<i>Poecile gambeli</i>	0	0	0	0	0	0	0
Mexican chickadee	<i>Poecile sclateri</i>	0	0	0	0	0	0	0
Juniper titmouse	<i>Baeolophus ridgwayi</i>	0	0	0	1	1	0	0
Bridled titmouse	<i>Baeolophus wollweberi</i>	0	0	0	1	1	0	0
Verdin	<i>Auriparus flaviceps</i>	0	0	0	0	1	0	0
Bushtit	<i>Psaltriparus minimus</i>	0	0	0	1	1	0	0
Red-breasted nuthatch	<i>Sitta canadensis</i>	0	1	0	0	0	0	0
White-breasted nuthatch	<i>Sitta carolinensis</i>	0	0	0	0	0	0	0
Pygmy nuthatch	<i>Sitta pygmaea</i>	0	1	0	0	0	0	1
Brown creeper	<i>Certhia americana</i>	0	1	1	0	0	0	1
Canyon wren	<i>Catherpes mexicanus</i>	0	0	0	1	1	1	0
Rock wren	<i>Salpinctes obsoletus</i>	0	0	0	1	1	0	0
Bewick's wren	<i>Thryomanes bewickii</i>	0	0	0	1	1	0	0
House wren	<i>Troglodytes aedon</i>	0	1	0	0	0	0	0
Winter wren	<i>Troglodytes hiemalis</i>	0	0	0	0	0	0	1
Blue-gray gnatcatcher	<i>Polioptila caerulea</i>	0	0	0	1	1	0	0
Black-tailed gnatcatcher	<i>Polioptila melanura</i>	0	0	0	1	0	0	0
Ruby-crowned kinglet	<i>Regulus calendula</i>	0	0	0	1	1	0	0
Golden-crowned kinglet	<i>Regulus satrapa</i>	0	1	0	0	0	0	0
Mountain bluebird	<i>Sialia currucoides</i>	0	0	0	0	0	0	1
Western bluebird	<i>Sialia mexicana</i>	0	0	0	0	0	0	0
Eastern bluebird	<i>Sialia sialis</i>	0	1	0	0	0	0	0
Townsend's solitaire	<i>Myadestes townsendi</i>	0	0	0	0	0	0	1
Hermit thrush	<i>Catharus guttatus</i>	0	1	1	0	0	0	0
Swainson's thrush	<i>Catharus ustulatus</i>	0	1	0	0	0	0	0
American robin	<i>Turdus migratorius</i>	0	0	1	0	0	0	0
Northern mockingbird	<i>Mimus polyglottos</i>	0	0	0	1	1	0	0
Bendire's thrasher	<i>Toxostoma bendirei</i>	0	0	0	0	0	0	0
Crissal thrasher	<i>Toxostoma crissale</i>	0	0	0	1	1	0	0
Curve-billed thrasher	<i>Toxostoma curvirostre</i>	0	0	0	1	1	0	0
Cedar waxwing	<i>Bombycilla cedrorum</i>	0	0	0	1	1	0	0
Phainopepla	<i>Phainopepla nitens</i>	0	0	0	1	0	1	0
Olive warbler	<i>Peucedramus taeniatus</i>	0	1	0	0	0	0	1
Red-faced warbler	<i>Cardellina rubrifrons</i>	0	1	1	0	0	0	0
Yellow-rumped warbler	<i>Setophaga coronata</i>	0	1	1	0	0	0	0
Grace's warbler	<i>Setophaga graciae</i>	0	1	1	0	0	0	0
Black-throated gray warbler	<i>Setophaga nigrescens</i>	0	0	1	1	1	0	0
Hermit warbler	<i>Setophaga occidentalis</i>	0	1	0	0	0	0	0
Townsend's warbler	<i>Setophaga townsendi</i>	0	0	0	1	0	0	1
Painted redstart	<i>Myioborus picta</i>	0	0	1	0	0	0	0
MacGillivray's warbler	<i>Geothlypis tolmiei</i>	1	0	0	0	0	0	0
Orange-crowned warbler	<i>Oreothlypis celata</i>	1	1	0	0	0	0	0
Lucy's warbler	<i>Oreothlypis luciae</i>	0	0	0	0	1	0	0

(continued)

Table 2—Continued

Common species name	Scientific name	Dec. for.	Mix.- conf. for.	Pine-oak for.	Brd. Evgr. wd.	Conf. wd.	Conf. ripa.	Pond. pine
Nashville warbler	<i>Oreothlypis ruficapilla</i>	0	0	0	0	1	0	0
Virginia's warbler	<i>Oreothlypis virginiae</i>	0	0	1	0	0	0	0
Wilson's warbler	<i>Cardellina pusilla</i>	0	0	0	1	0	0	0
Abert's towhee	<i>Melospiza aberti</i>	0	0	0	0	1	0	0
Green-tailed towhee	<i>Pipilo chlorurus</i>	0	0	0	1	1	0	0
Canyon towhee	<i>Melospiza fusca</i>	0	0	0	1	1	0	0
Spotted towhee	<i>Pipilo maculatus</i>	0	0	0	0	0	0	0
Rufous-crowned sparrow	<i>Aimophila ruficeps</i>	0	0	0	1	1	0	0
Black-throated sparrow	<i>Amphispiza bilineata</i>	0	0	0	1	1	0	0
Lark sparrow	<i>Chondestes grammacus</i>	0	0	0	0	0	0	0
Black-chinned sparrow	<i>Spizella atrogularis</i>	0	0	0	1	1	0	0
Chipping sparrow	<i>Spizella passerina</i>	0	0	0	1	1	0	0
White-crowned sparrow	<i>Zonotrichia leucophrys</i>	0	0	0	0	1	0	0
Dark-eyed junco	<i>Junco hyemalis</i>	0	0	0	1	1	0	0
Yellow-eyed junco	<i>Junco phaeonotus</i>	0	1	1	0	0	0	0
Hepatic tanager	<i>Piranga flava</i>	0	0	0	1	1	0	0
Western tanager	<i>Piranga ludoviciana</i>	0	0	0	0	0	0	0
Summer tanager	<i>Piranga rubra</i>	0	0	0	0	1	0	0
Northern cardinal	<i>Cardinalis cardinalis</i>	0	0	0	1	1	0	0
Pyrrhuloxia	<i>Cardinalis sinuatus</i>	0	0	0	0	1	0	0
Black-headed grosbeak	<i>Pheucticus melanocephalus</i>	0	0	0	0	0	0	0
Blue grosbeak	<i>Passerina caerulea</i>	0	0	0	1	0	0	0
Lazuli bunting	<i>Passerina amoena</i>	0	0	0	0	1	0	0
Eastern meadowlark	<i>Sturnella magna</i>	0	0	0	0	0	0	0
Western meadowlark	<i>Sturnella neglecta</i>	0	0	0	0	1	0	0
Brown-headed cowbird	<i>Molothrus ater</i>	0	0	0	1	1	0	0
Hooded oriole	<i>Icterus cucullatus</i>	0	0	0	0	1	0	0
Bullock's oriole	<i>Icterus bullockii</i>	0	0	0	1	1	0	0
Scott's oriole	<i>Icterus parisorum</i>	0	0	0	1	1	0	0
Pine siskin	<i>Spinus pinus</i>	0	1	0	0	0	0	1
Lesser goldfinch	<i>Spinus psaltria</i>	0	0	0	1	1	0	0
Cassin's finch	<i>Carpodacus cassinii</i>	0	1	0	0	0	0	0
House finch	<i>Carpodacus mexicanus</i>	0	0	0	1	1	0	0
Evening grosbeak	<i>Coccothraustes vespertinus</i>	1	1	0	0	0	0	0
Red crossbill	<i>Loxia curvirostra</i>	0	0	0	0	0	0	1

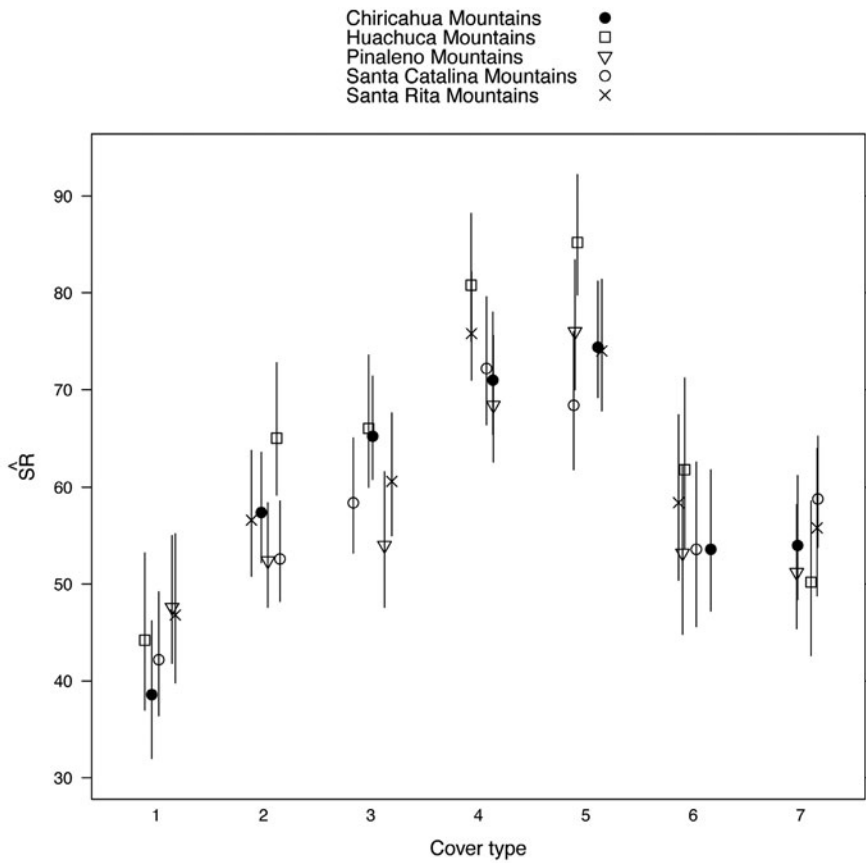


Figure 2—Median posterior estimates of average species richness (SR) and 95% Bayesian credible intervals over all years from 1991 to 1995 for the five Sky Island mountain ranges of southeastern Arizona, USA. Estimates are separated by cover type (1 = deciduous forest, 2 = mixed-conifer forest, 3 = pine-oak forest, 4 = broadleaf evergreen woodland, 5 = conifer woodland, 6 = conifer riparian, 7 = ponderosa pine).

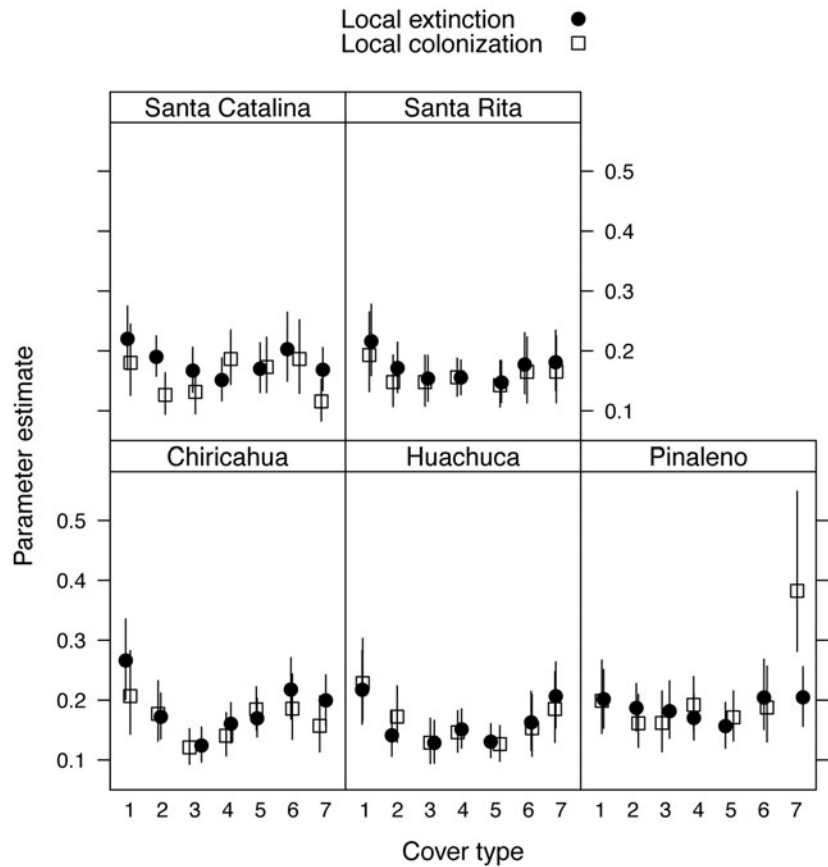


Figure 3—Median posterior estimates of local extinction and local colonization and 95% Bayesian credible intervals over all years from 1991 to 1995 for the five Sky Island mountain ranges of southeastern Arizona, USA. Estimates are separated by cover type (1 = deciduous forest, 2 = mixed-conifer forest, 3 = pine-oak forest, 4 = broadleaf evergreen woodland, 5 = conifer woodland, 6 = conifer riparian, 7 = ponderosa pine).

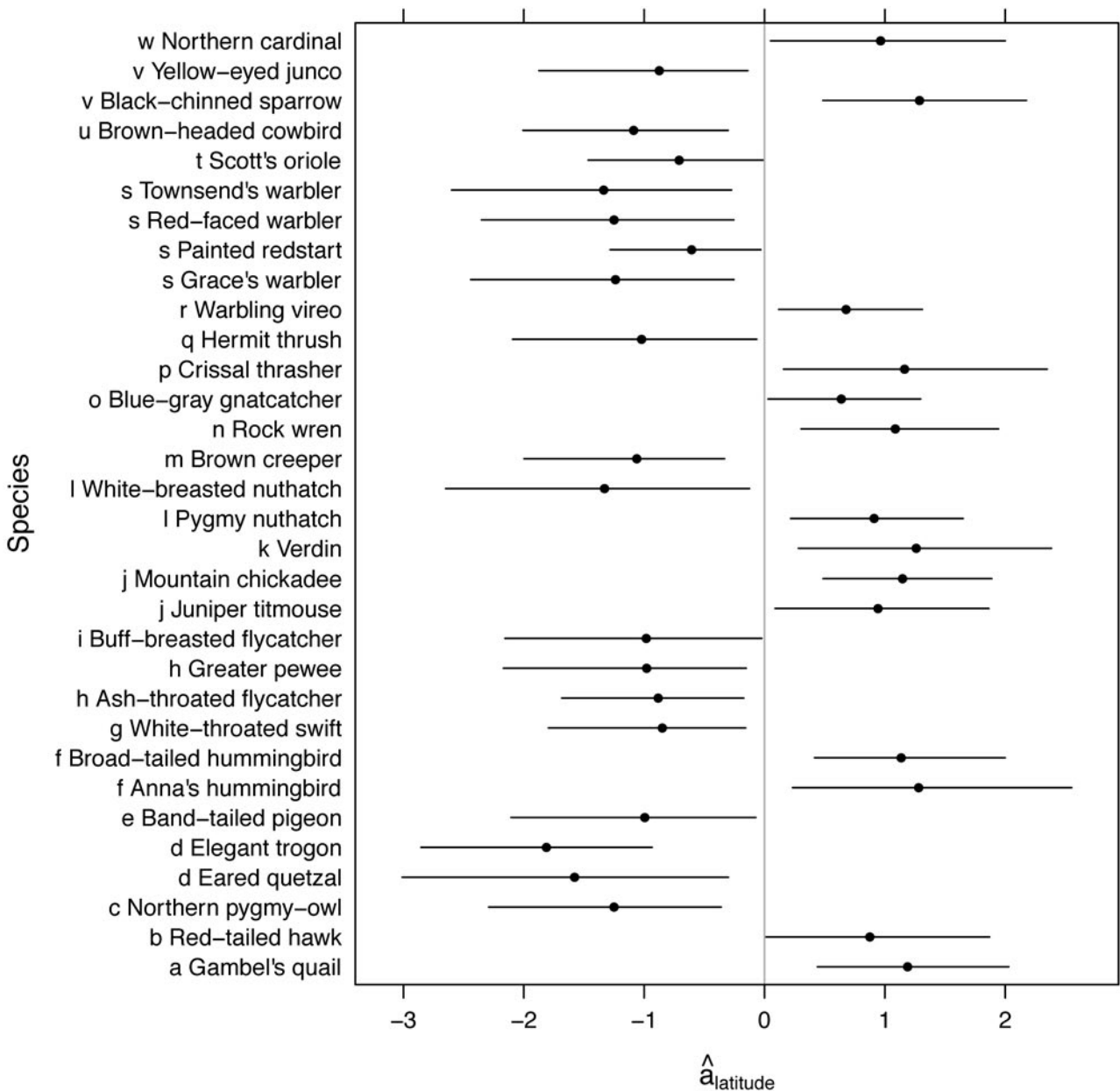


Figure 4—Significant median posterior estimates for the latitude slope parameter ($\hat{\alpha}_{latitude}$) and 95% Bayesian credible intervals of individual avian species from a study conducted from 1991 to 1995 in five Sky Island mountain ranges of southeastern Arizona, USA. Positive associations indicate that the probability of occupancy for those species increases with increasing latitude, while negative associations indicate probability of occupancy decreases with increasing latitude. Scientific names for these species are given within Table 2. Species are ordered according to taxon or family group (letters indicate separate groups).

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Biodiversity Effects on Ecosystem Function Due to Land Use: The Case of Buffel Savannas in the Sky Islands Seas in the Central Region of Sonora

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Abstract—Buffel savannas have been an important landscape on cattle grazing ranches in Sonora over the past 50 years or more. Changes in land use result in biodiversity changes that may produce ecosystem functional changes; however, these are less well documented. Although fire driven processes have been proposed for Buffel savannas, this is not generally the case, and other processes seem to be driving ecosystem function. Several years of studying above- and below ground processes allow us to propose how microclimate, water and nutrient dynamics change in established Buffel savannas, as well as how biodiversity changes may affect functional processes in arid and semiarid ecosystems. Water and nutrient biogeochemical cycles changed in Buffel dominated savannas in comparison with those in natural ecosystems, following land use changes. Our findings may be extrapolated to other highly invaded areas where Buffel grass is becoming a dominant exotic species.

Keywords: biodiversity effects on ecosystem function, Buffel savanna, desert scrub, Sonoran Desert, soil microclimate, soil moisture.

Land Use in Arid Sonoran Ecosystems

The Sonoran Desert in the States of Sonora, Baja California (North and South), Arizona and California covers close to 300,000 Km². It has important gradients of increasing plant species diversity from north (*Larrea* dominated ecosystems) to south in México and from west to east (with increasing tropical floristic influence), which results in a large plant functional diversity and biological forms (Peinado and others 1990; Shreve 1942). Those changes in taxonomic and functional biodiversity, following phytogeographic and aridity gradients, make the Central Sonora Region (CSR) (broadly limited to 28 - 30°N and 102 - 106°W), the ecotone for those two major gradients, and thus, a particularly important area for ecological and biogeographical studies. The biological importance of the region is because it is the northern most limit to a large number of neotropical species, as well as the southernmost limit to many nearctic species (Rzedowski 1978). It is important as well because it is an arid ecotone where large speciation events (Stebbins 1952), high endemism (Shreve and others 1964; Turner and others 1995) and ecological legacies (Castellanos 1992; Castellanos and others 2010) are found.

Land use and cover change have been rapid and greatly modified by cattle ranching in the last half century. Cattle grazing was introduced into Northwestern Mexico and the Central Sonora Region (CSR) during the late 1600's (Camou 1998; Castellanos and others 2010). Large herds of cattle have been present for over 400 years in the CSR, diminishing palatable forage plant species, increasing shrubland and degrading habitat (Aguirre-Murrieta and others 1974; COTECOCA 2002). Because of its aridity and dryness, Sonora grazing lands are known to support as few as one animal unit per 20 - 30 hectares (Aguirre-Murrieta and others 1974). However, increasing opportunities for cattle export to the United States in the 1950's led to a change in the ranching technological paradigm in Sonora (Bravo-Peña and others 2010; Camou 1998; Castellanos and others 2010). Socioeconomic drivers, such as increasing cattle market demands, led to overstocking and increasing habitat degradation, which led to increasing exotic buffel (*Pennisetum ciliare* L.) grasslands being established in Sonora, following research from Texas AM University (Johnson and Murrieta 1992). In order to increase land productivity to support market needs, extensive tracts of land were converted to intensive monocultures of *P. ciliare*.

Over the last 40-50 years in Sonora, a common practice has been to chain and bulldoze large tracts of terrain, clearing (in early years all, but more recently) most shrubs and trees, seeding buffel grass and rotating cattle seasonally. Despite the apparent productive advantages, this massive disturbance has posed a number of ecological challenges over the years, not only because it decreases species richness and plant diversity (Castellanos and others 2002; Saucedo-Monarque 1994; Saucedo-Monarque and others 1997), increases the potential for soil erosion (Perramond 2000; Saucedo-Monarque 1994), changes

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

microclimatic soil conditions (Castellanos and others 2002); but also because it decreases important soil nitrogen (Castellanos and others 2002; Dalal and others 2005; Ibarra-Flores and others 1999), and changes nutrient dynamics (Castellanos and others 2010; Celaya-Michel and others 2011; López 2007).

Shrubland conversion to buffel savannas has changed biodiversity composition and ecosystem structure in such a way that no detailed knowledge exists on how those highly modified ecosystems will function, remain, change or affect different ecosystem processes, as well as biotic and trophic links. Buffel savannas dominated by a highly invasive grass species are an important part of the landscape in Sonora, but their ecological effects are unknown (Arriaga and others 2004). We believe that a better understanding of how introduced buffel savannas functions is needed and can help to understand the short and long-term ecological implications of this management policy, such as to understand some of the main causes for its spreading, as well as to help us establish better management practices to control its spreading into native adjacent ecosystems. Our approach also provides some badly needed basic knowledge on how Sonoran Desert and arid ecosystems function.

Over the last 20 years we have studied paired sites in different arid ecosystems in the Central Sonora Region. Paired sites (buffel savannas and “native” vegetation cover) have been studied in order to answer some important questions in relation to the role of biodiversity in ecosystem function:

- How are microclimate, soil moisture, and fertility dynamics modified in native compared to buffel savannas?
- What are the changes in ecosystem nitrogen dynamics and how do they relate to changes in structure and species composition?
- How are ecosystem degradation and resilience changed in a nearly monospecific-dominated ecosystem of buffel savannas?

Biodiversity Change and Ecosystem Function

Biodiversity is an important component of ecosystems and its qualitative and quantitative changes have been found to affect its function, an important consideration with increasing land cover use and change (Hooper and others 2005; Naeem and others 2002; Schulze and others 1994). A well-established paradigm relates biodiversity with net primary productivity (Tilman 1988; Tilman and others 2002; Tilman and others 1997; Wright and others 2006) and ecosystem stability (Tilman and others 2002; Tilman and others 2006).

Even though buffel savannas have been proposed as a management alternative to increase land net primary productivity, some studies question that such a goal has been achieved. Using NDVI, as a proxy to measure vegetation productivity, has shown that plant productivity is much lower than proposed or expected in a range of conditions along a rainfall gradient (Bravo-Peña 2009; Romo 2006), in the Central Region of Sonora and a region north of it (Franklin and others 2006).

Questions remain on how changes from natural ecosystems to buffel savannas affect biodiversity and biotic links at different levels, how and what ecosystem processes change, and how stability of these induced and simplified ecosystems is modified.

Structural Changes in Plant Cover

Plant removal for buffel grass establishment changed plant structure and cover (fig.1). While the herbaceous stratum is significantly increased by buffel cover in the savanna, total plant cover diminishes

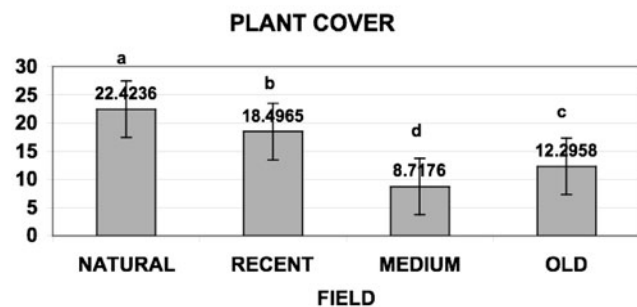


Figure 1—Changes in plant cover in Buffel savannas of different age of establishment. Old (≥ 30 yrs), Medium (10 - 30 yrs) and Recent (0 - 10 yrs). Natural is the predominant native vegetation at the site (modified from Romo (2006) and López (2007)).

compared to native vegetation stands. It has been found (Romo 2006; Lopez 2007) that cover could further diminish after some 30-40 years of savanna establishment to about half compared to natural vegetation.

We have proposed that a “green rush” effect drives cattle ranchers to adopt buffel savanna establishment (Bravo and others 2010a). The effect happens after the dry season and with the first summer monsoon rains. Once buffel has been established, because it is a fast growing herbaceous perennial species, it has the ability to immediately leaf-out after the very first rainfall pulses, producing an immediate “greenness” given that the whole savanna biomass is biologically, physically, and visually concentrated in only one vegetation stratum. Meanwhile, most neighboring plant species within native woody vegetation will green out later, resulting in large patches of brown and green because the greenness is distributed multi-dimensionally over the landscape.

Soil Abiotic Controls

Soil Temperature and Moisture

Temperature and moisture are important drivers of ecosystem processes in the soil. Mean annual soil temperatures at 10 cm were not different at different sites of buffel cover, but their temperature dynamics were different (fig. 2). As expected, maximum and minimum soil temperatures were found in bare areas (ISN and ISB), which showed the largest soil temperature fluctuations in a given time.

Vegetation cover damps soil temperature in fall and winter months and during most of the year its coefficient of variation was the lowest. Higher minimum soil temperatures were found under *O. tesota* trees and under buffel grass. Mean soil temperatures were higher under trees and lowest in the savanna because of large temperature fluctuations during the day. Buffel microsites had the lowest soil maximum temperatures during fall and winter but not in summer when PFB had about 15 - 20 °C lower temperatures compared to similar microsites in natural vegetation (PFN).

Largest daily and seasonal variations in soil temperatures in bare and buffel areas may have important implications to establishment of successional native species (Morales-Romero and others 2008; Saucedo-Monarque 1994).

Soil maximum (T_{max}) and average (T_{av}) temperatures as well as minimum (T_{min}) and average (T_{av}) air temperatures were significantly related to soil respiration. Highest significances were found between soil respiration and T_{max}. Soil respiration was also directly related to volumetric soil moisture at all times during the

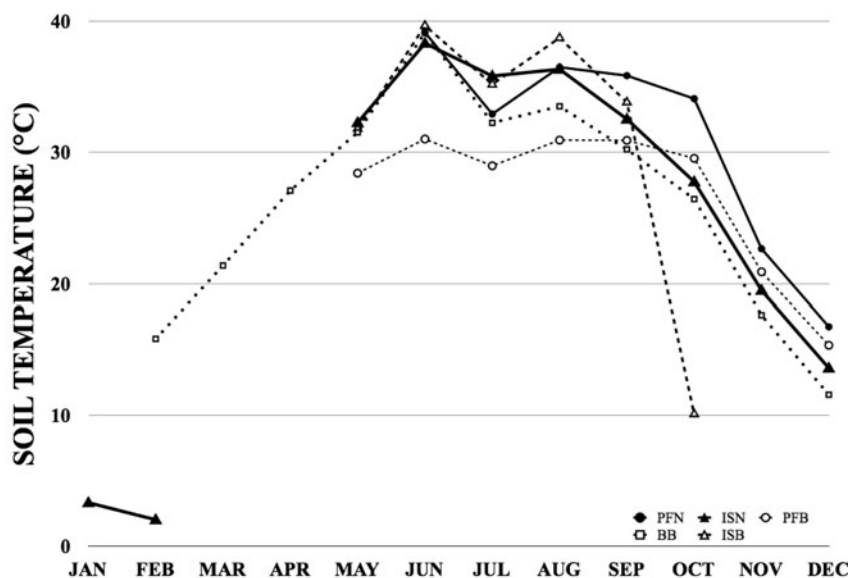


Figure 2—Mean soil temperature at different microsites during the year. PFN = under ironwood (*O. tesota*) trees in natural vegetation, PFB = similar but within the Buffel savanna; ISN = interspace (bare areas between trees, shrubs or herbaceous perennials) in natural vegetation, ISB = similar but within Buffel savannas; BB = under the canopy of Buffel grass.

year, although this relationship decreased with depth to 50 cm and deeper.

Soil moisture changed with site (table 1; fig. 3), year, and time of the year. Soil moisture in the buffel savanna was significantly lower because lower soil moisture in the interspaces and under *O. tesota* trees, compared to similar habitats in natural ecosystems. Soil moisture under ironwood in the savanna (PFB) had the lowest mean soil moisture (2.60 ± 2.2 g H₂O g⁻¹ soil $p < 0.01$) but not significantly lower than the one found for the same microsite in natural vegetation (PFN, 4.15 ± 4.9 g H₂O g⁻¹ soil). Although not expected, because of late summer and early fall rainfalls during the last 2 years, soil moisture was higher at depths below 100 cm in sites with increasing aboveground leaf cover, including fewer than 100 cm in buffel grass. This is below depths of usable soil moisture (close to 60 - 70 cm in buffel), and depths of 130 - 150 cm below *O. tesota* canopies.

Soil Biotic Interactions

Termite Activity

Termite diversity was affected by changes in plant cover and structure in the natural vegetation and buffel savanna. In both ecosystems, termite richness did not change and the same six species were found in both ecosystems throughout the year (fig. 4). Of the species found, *Gnathamitermes perplexus* (41%) and *Heterotermes aureus* (33%)

were the two most frequent termite species. Other species were *Amitermes* spp, *Hoplotermes* spp and *Tenuirostritermes* spp as well as an unidentified Amitermitinae species.

Small numbers of plots yielded small numbers of termite species. Expected termite richness ("Mao Tau" computed by the EstimateS® program using pooled plot data) was almost 25% higher for natural systems (8 spp) compared with buffel savanna (S_{obs} in fig. 4). "Chao2," another EstimateS richness output that assumes a different distribution of sampling error, gave similar results, with highest values for termite species richness during September on natural sites. During winter months (not shown on fig. 4), richness was lowest in natural systems. Chao2 curves confirm that the sampling effort on study sites was appropriate (fig. 4).

Termite presence, seasonal activity, frequencies and trophic substrates did change between natural and buffel savanna ecosystems. Seasonal presence of termite species changed in both ecosystems. buffel savannas termites were most active during autumn-winter seasons, while major seasonal activity in natural ecosystems occurred at the end of summer-early fall season under *O. tesota* trees. Changes were also found in the interspaces — bare zones between species — with most important termite activity at the end of winter-spring seasons, while under buffel in the Savanna, activity periods were at the end of summer rainy season and during winter months. In bare unprotected zones, diversity was lower and major activity was found during spring.

An important finding was that *Gnathamitermes perplexus*, the most common species in the buffel savanna, was found foraging mostly

Table 1—Changes in water availability at different depths in native vegetation and Buffel savanna sites. Volumetric water percentage obtained with TRIME® access tubes.

	Natural	SABANA	N	F	P
	Mean±s.e.	Mean±s.e.			
0 to 50 cm	3.38±0.28 ^a	33.25±.25 ^a	30	0.1251	0.072*
0 to 100 cm	8.22±0.52 ^a	5.78±.47 ^b	30	12.140	0.0007**
0 to 150 cm	11.56±0.75 ^a	7.65±.68 ^b	30	14.8735	0.0002**

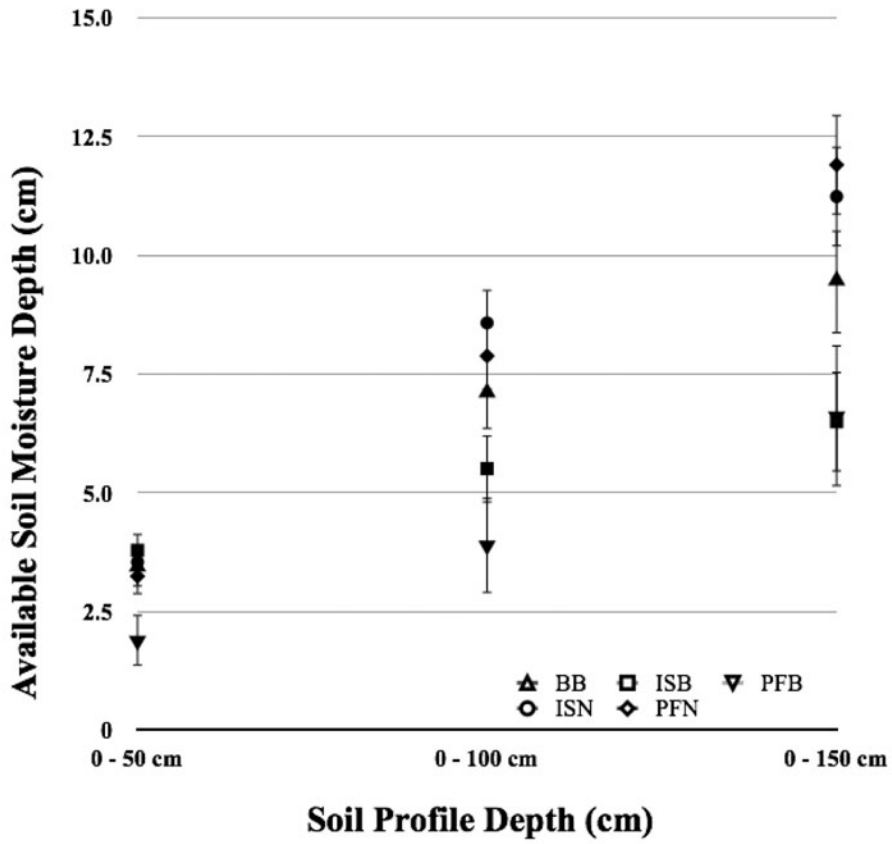


Figure 3—Changes in available soil moisture (amount of water in cm, in a profile), for different microsites in natural and Buffel savanna sites.

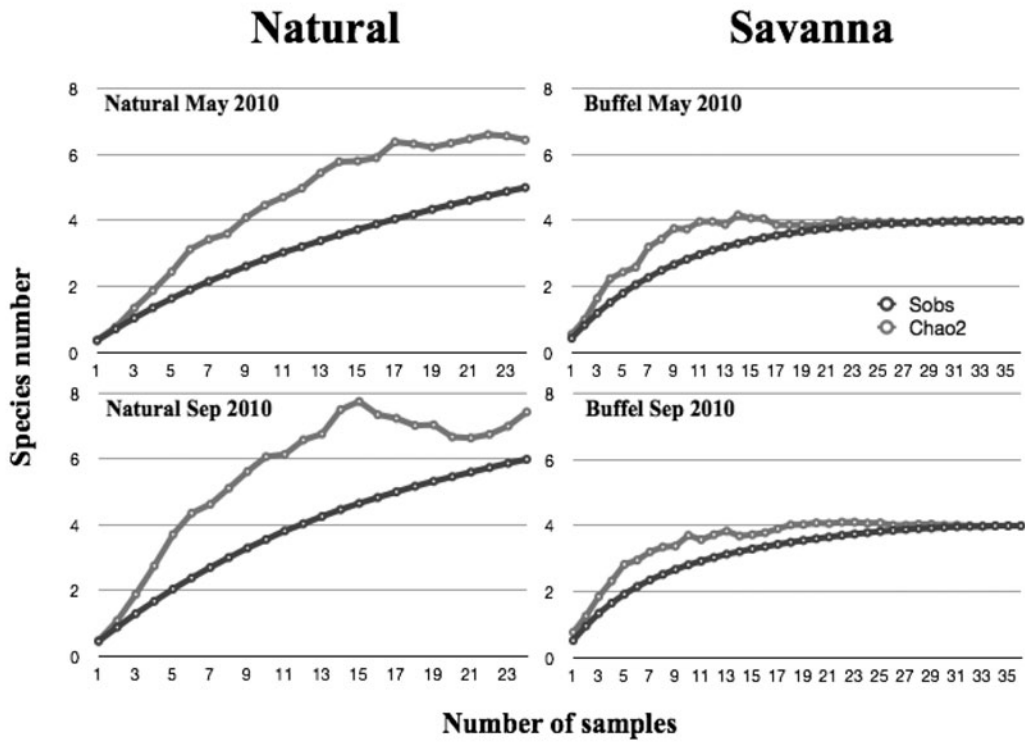


Figure 4—Expected termite richness in natural and Buffel savanna sites using Estimates®.

Table 2—Significant relationships among temperature, soil moisture and termite frequencies. Positive signs represent direct relationship between variables. Negative signs denote inverse relationship between variables.

Species	Maximum air temperature (T _{Amax})	Minimum air temperature (T _{Amin})	Minimum soil temperature (T _{Smin})	Average soil temperature (T _{Savg})	Soil moisture (10 cm)	Soil moisture (100 cm)	Soil moisture (150 cm)
<i>Amitermes</i>					–		+
<i>Gnathamitermes</i>		–	–	–			
<i>Heterotermes</i>		–	–				
<i>Hoplotermes</i>							
Sp 1							–
<i>Tenuirostritermes</i>	–		–	–		+	

on this grass species, behaving as an opportunistic species, changing its trophic substrate to the more abundant buffel litter. In a different study under Sonoran Desert conditions in Arizona, higher activity of *Gnathamitermes perplexus* was found in the range of 9 to 49 °C, while *Heterotermes aureus*, had a slightly lower, 7 to 47 °C, range (table 2; Haverty 2001).

Discussion

Chambers and others (2007) mention the hypothesis of fluctuating resources and say that invasibility is related to the availability of resources. In particular, invasibility increases if increasing resources are not utilized by natives. The availability of resources to buffel grass will be related to (a) an increase in supply reliability or (b) a decrease in uptake by natives. Many studies relate increased availability of nitrogen with increased invasibility.

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Biogeography and Diversity of Pines in the Madrean Archipelago

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Abstract—Pines are important dominants in pine-oak, pine and mixed-conifer forests across the Colorado Plateau, southern Rocky Mountains, Sierra Madre Occidental, and in the intervening Sky Islands of the United States-Mexico borderlands. All 17 native species of pines in the Sky Islands region or their adjacent mountain mainlands reach the northern or southern margins of their geographic ranges and most (12) have Madrean vs. Petran affinities. We compiled data on the occurrence and diversity of pines across 31 Sky Islands based on extensive fieldwork that complemented data from museum collections. Lower and smaller mountains supported zero to four species of pines whereas higher ones with greater area and thus larger population sizes supported five to seven species. Diversity of pines increased by 0.34% with each 1% increase in area (km²) of forest in a mountain range with similar effects for maximum elevation ($P < 0.001$); diversity decreased by 0.70% with each 1% increase in distance (km) to the nearest mainland ($P < 0.015$). Forest area explained >2 times more variation in pine diversity ($R^2 = 0.42$) than distance from the nearest mainland ($R^2 = 0.19$), suggesting that larger population sizes of pines on bigger mountains reduce rates of stochastic extinctions and that this process is more important than dispersal limitation in driving pine diversity. Although pine species have no legal conservation status in the Sky Islands, pine forests, especially those on small isolated mountaintops, are among the most threatened plant communities in this region due to increased fire disturbance, insect outbreaks, and climate change.

Introduction

The genus *Pinus* includes about 110 species and is the largest genus of conifers and among the most widespread trees in the northern hemisphere. Mexico and Central America support the highest diversity of pine species (47) including 30 that are endemic to Mexico, whereas a second center of diversity of about 25 species occurs in eastern Asia (Price and others 1998). As noted in 1942 by Howard Gentry, Mexico is a cornucopia of pine species with high diversity that crosses the United States-Mexico border into the Madrean Sky Islands region (Martin and others 1998). Of 17 native species of pines in the Sky Islands and their adjacent cordilleran mainlands, 12 have stronger biogeographic affinities to the more southerly Sierra Madre Occidental (SMO). Notably, in this broad biogeographic transition zone, all 17 species of pines reach the northern or southern margins of their geographic ranges.

We studied the distribution of pines in the Madrean Sky Islands region and assessed how mountain area, elevation, and distance to the nearest mainland (SMO or Colorado Plateau) affected diversity of pines across 31 Sky Island mountain ranges in the United States and Mexico. We present these results and discuss implications for understanding the distribution, biogeography, and conservation of pines in the region.

Methods

Study Area

We considered three geographic areas: 1) mountain ranges across the entire Sky Islands region in southern Arizona, southwest New Mexico, northeast Sonora, and northwest Chihuahua, 2) the southern Colorado Plateau and Rocky Mountains (CP-RM) in southern Colorado, central and northern Arizona and northern and western New Mexico, and 3) the continuous highlands of the northern SMO in east-central Sonora and west-central Chihuahua that are located directly south and east of the Sky Islands region.

The Sky Islands region encompasses the Apachian subprovince of the Madrean floristic province (McLaughlin 1995, 2007, 2008) and is bounded to the north by the Gila River or by a level grassland plain in lowest saddle on the Continental Divide (1370 m). Although the region's southern boundary has been defined based on the biogeographic

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affinities of the local flora, it is less clear exactly where it should be placed. The east and west boundaries of the Sky Islands region are more well defined by vast level plains of low relief beyond the Big Hatchet mountains in New Mexico and the Baboquivari mountains in Arizona/Sierra el Humo in Sonora, respectively (Marshall 1957; Flesch and Hahn 2005).

Design

We considered mountain ranges that supported at least one species of pine in the flora and that supported woodlands of oaks and pines that were isolated and discrete from other such patches. Mountain ranges containing pines have peak elevations greater than 1885 m, and we considered mountain ranges as discrete (a) if they were not connected by elevations >1555 m (the highest saddle with a wide grassland ecotone); (b) if there were no continuous woodland across a saddle if higher than 1555 m; and (c) if continuous woodland exists without pines if lower. The role of vegetation was important in determining three: (1) a desert grassland saddle at 1675 m between the Animas and Pan Duro/Sierra San Luis mountains separates them as islands on the eastern edge of the Sky Island region bordered by drier desert grassland and Chihuahuan desertscrub; (2) a continuous oak woodland saddle at 1350 m between the Sierra de los Ajos/Púrica and the Sierra Juriquipa that has a broad area connecting the ranges (on a rapidly rising Pacific slope gradient); and (3) a problematic zone noted by McLaughlin (1995) that includes highland extensions of SMO woodlands in the Sierra Hachita Hueca and El Gato (Huachinera) with saddles >1555 whereas the 2400 m high Sierra Bacadéhuachi is an island because of the low 1340 m saddle of oak woodland that separates Sierra Bacadéhuachi from more extensive woodlands of the SMO.

Data Collection and Analysis

We compiled information on the presence and distribution of pines during many years (1995–2011) of fieldwork. We supplemented these data with historical records from museum records and databases such as the Southwest Environmental Information Network (SEINet) and Madrean Archipelago Biodiversity Assessment (MABA) floral database (<http://www.madrean.org>) dating back to 1880. Information on pine distribution outside the Sky Islands region for determining extent and geographic center of species ranges was obtained from Little (1999).

Because the taxonomy of some species in the genus *Pinus* is equivocal, we verified species by examining representative specimens and used nomenclature from published sources (Farjon and Styles 1997; Ferguson and others 2001; García-Arevalo and González-Elizondo 1998; Kral 1993; Price and others 1998). Recent phylogenetic analyses based on molecular data and phytochemistry have provided new information on some of these taxonomic problems. Definitions of some of the more problematic species are defined in the Appendix.

To assess the effects of large-scale landscape and biogeographic factors on diversity of pines in the Sky Islands region, we used four variables. As a response variable we calculated the number of *Pinus* species found in the flora of each mountain island. As explanatory variables we considered total area of woodland and forest (km²) that could potentially support pines, the maximum elevation of each mountain range from sea level to summit (m), and the distance from each mountain range to the nearest mainland or potential source population of immigrants (km; CP-RM or SMO). We only considered mountains that supported pines because we were interested only in

these relict and isolated populations of the Holocene, rather than the broader dispersal routes of past climates.

To estimate the area of woodland and forest vegetation in each Sky Island, we used data from The Nature Conservancy's Apache Highlands Ecoregion study for mountains in Arizona, New Mexico, and northern Sonora and Chihuahua (Marshall and others 2004). For other mountain ranges in Mexico we used data from the Mexican National Forest Inventory and combined comparable vegetation communities (Palacio-Prieto and others 2000; Velazquez and others 2000). Using this first data source, we calculated woodland area for each mountain range by summing the areas among seven vegetation communities: Madrean Encinal, Madrean Oak-Pine Woodland, Pinyon-Juniper Woodland, Interior Chaparral, Montane Mixed-Conifer Forest, Ponderosa Pine Forest and Woodland, and Sub-alpine Spruce-Fir Forest and Woodland. For this second data source, we computed comparable estimates by summing the area of Chaparral, Bosque de Encino, Tascate, Encino-Pino, and Pino-Encino.

We used estimates of the maximum elevation of each Sky Island from USGS and INEGI topographic maps rounded to nearest 5 m. Distance estimates between each Sky Island and the CP-RM and SMO were obtained from 1:500,000 scale NOAA Sectional Aeronautical Charts and from Google Earth. We measured distances between the summit of each mountain range and a fixed reference point for each mainland. The CP-RM reference point was located at the southern edge of this highland at 2740 m elevation (33°33'N, 109°20'W; near U.S. Highway 191 south of Hannagan Meadow, Arizona) and the SMO reference point was at the north edge of this highland at 2690 m elevation (30°33'N, 108°37'W; Mesa las Guacamayas, Chihuahua).

To model the effects of area, elevation, and isolation on pine species diversity, we log transformed each variable and used simple linear regression to estimate the slope of each individual effect and the total variation in pine diversity that was explained by each explanatory variable. To assess the combined effects of different explanatory variables on pine diversity, we used multiple linear regression. Because maximum elevation was correlated with area of woodland and forest ($r = 0.41$, $P = 0.024$), we only used area and distance in the model. Because estimates from two mountain ranges were outliers, we conducted some analyses with and without these values. We also assess the effects of distance from the CP-RM or SMO on diversity of northern and southern pine species, respectively.

Results

Pine Species Occurrence and Diversity

A total of 17 pine species occur in the study area (table 1). Nine species of pines occur in 31 Sky Islands including five species that are widely distributed in the Sky Islands. The northern mainland (CP-RM) supports two species of pines (*Pinus aristata* and *P. contorta*) that do not occur at the southern edge of the Colorado Plateau or in the nearby Sky Islands. The southern mainland (SMO) supports five species (*P. herrerae*, *P. leiophylla*, *P. lumholtzii*, *P. maximinoi*, and *P. oocarpa*) in the north-central portion of the range that do not occur at the northern edge of the SMO or in the Sky Islands; a sixth Madrean species of pine (*P. cembroides*) does occur at the northern edge of the SMO but not in the Sky Islands.

The highest diversity of pines in a single Sky Island is seven species, occurring in the Chiricahua Mountains, the second highest elevation island. Of the other high islands, three have six species (Pinaleno, Huachuca, and Santa Rita) and the lower wider Galiuro Mountain also have six. The most diverse Sky Islands have about the same number of species as found at the edge of the CP-RM mainland (seven), in

Table 1—Biogeographic affinities and presence (X) of nine *Pinus* species in 31 Sky Islands and adjacent mainlands, with peak elevations for each island, from north (left) to south (right) in (A) southwestern U.S. and (B) northwestern Mexico.

Floristic Subprovince	<i>Pinus</i> Species	A																	B																			
		(Colorado Plateau)	Santa Teresa	Pinaleño	Galliero-Winchest.	Santa Catalina	Rincon	Little Dragoon	Dragoon	Chiricahua	Whetstone	Sierrita	Baboquivari	Santa Rita	Huachuca	Atascosa	Mule	Big Hatchet	Animas	Pan Duro-Pelon.	San José	Chivato	Pinito	Cibuta	Mariquita	Ajos	Azul	Madera Imuris	San Antonio	Tigre	Madera Oposura	Aconchi	Bacadéhuachi (Sierra Madre)					
Colorado Plateau and Rocky Mountains ^a	<i>P. flexilis</i>	X			X																																	
	<i>P. edulis</i>	X	X	X	X			X										X																				
	<i>P. ponderosa</i>	X	X	X	X	X	X		X	X			X	X						X															X			
Madrean ^b	<i>P. strobiformis</i>	X	X	X	X	X		X					X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
	<i>P. chihuahuana</i>		X	X	X	X	X		X				X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	<i>P. arizonica</i>			X	X	X	X		X				X	X				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	<i>P. discolor</i>		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	<i>P. engelmannii</i>								X					X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
	<i>P. yecorensis</i>													X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
TOTAL species per island:		4	6	6	5	5	0	1	7	2	1	1	6	6	2	2	1	5	5	5	5	2	3	2	5	5	4	3	3	5	4	3	5					
Elevation (m)		2525	3270	3240	2790	2640	2050	2290	2975	2350	1885	2360	2880	2885	1965	2245	2540	2600	2520	2520	2160	2200	2000	2480	2615	2440	2000	2220	2440	2320	2180	2400						

^a Two additional species do not reach the Sky Islands: *P. aristata*, *P. contorta*.

^b Six additional species do not reach the Sky Islands: *P. cembroides*, *P. herrerae*, *P. leiophylla*, *Pl lumholtzii*, *P. maximinoi*, *P. oocarpa*.

the CP-RM proper (six), or at the edge of the SMO (eight) although the species present in the north and south are different. With 13 pine species, the SMO has a much higher diversity than any individual Sky Island, although at any one location in the northern SMO only as many as 7 species co-occur.

Three biotic provinces (Madrean, Cordilleran, Apachian) of Dice (1943) are represented by the floristic elements defined by McLaughlin (2008). Of the 17 species of pines in our study area, five (~30%) have

affinities to the northern floristic element of the CP-RM subprovinces and 12 (~70%) have affinities to a southern floristic element of the Madrean floristic province. Three Madrean element pines (*Pinus chihuahuana*, *P. discolor*, and *P. arizonica*) extend as far north as the edge of the CP-RM, and a fourth (*P. strobiformis*) extends onto the Colorado Plateau. One CP-RM element pine (*P. ponderosa*) extends to the edge of the SMO and onto the SMO proper in the northern part only.

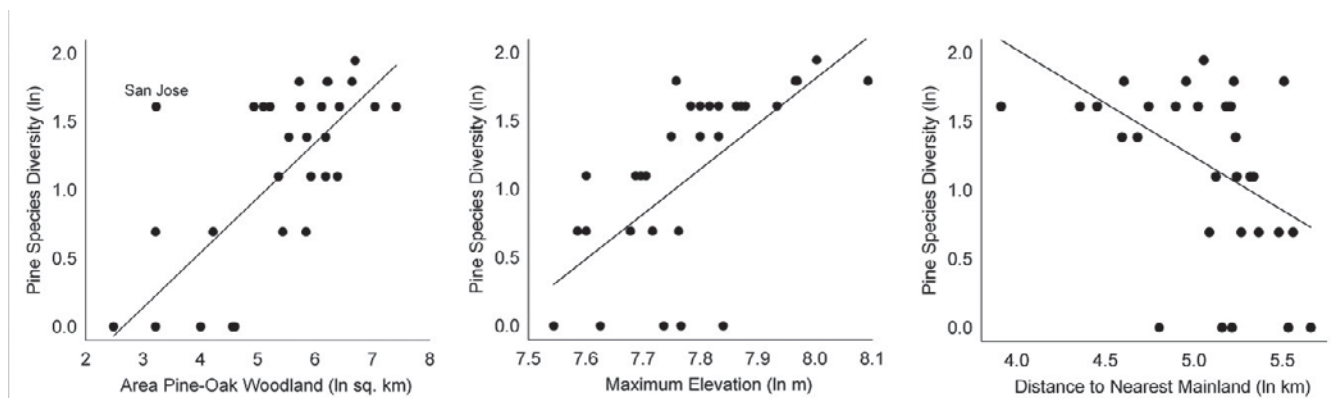


Figure 1—Relationship of pine species diversity (ln) to woodland area, elevation, and distance to the nearest mainland (left to right) in all 31 Sky Island mountain ranges in the Madrean Archipelago. The regression line is the estimate of diversity for each effect. An outlier for the effect of area is Sierra San José.

Drivers of Diversity

Both the area of woodland habitat and the maximum elevation of a Sky Island have large effects on diversity. Pine species diversity increased by $0.34 \pm 0.074\%$ (\pm SE) with each 1% increase in area of woodland (km²) that was present in a Sky Island ($P < 0.0001$; fig. 1) and by $3.20 \pm 0.074\%$ (\pm SE) with each 1% increase in elevation ($P < 0.0001$; fig. 1). The effect of area was large even with a Sky Island outlier, Sierra San José included. Island isolation also affected pine species diversity but explained less variation than area or elevation when considered independently (table 2). Species diversity decreased by $0.70 \pm 0.27\%$ (\pm SE) with each 1% increase in distance to nearest mainland ($P = 0.015$; fig. 1). We found that one Sky Island was an outlier with respect to the distance effect; when Big Hatchet was removed the effects of distance on pine diversity increased (table 2). Distance to the nearest mainland was not as correlated with either woodland area or elevation ($r = -0.37$, $P < 0.05$ and $r = -0.35$, $P = 0.05$ respectively).

When only pines species in the northern element were considered for each island, distance to CP-RM had a large effect on species diversity (table 3); species diversity decreased by $0.93 \pm 0.15\%$ (\pm SE) with each 1% increase in distance from the CP-RM ($P < 0.0001$; fig. 2). When only pines in the southern element were considered for each island, distance to the Sierra Madre had much less of an effect on pine species diversity; species diversity decreased by $0.36 \pm 0.18\%$ (\pm SE) with each 1% increase in distance from the SMO ($P = 0.065$; fig. 2) and by $0.47 \pm 0.15\%$ (\pm SE) with each 1% increase in distance once Big Hatchet was removed ($P = 0.004$; table 3).

When the combined effects of habitat area and isolation were considered, there was some evidence that both woodland area and isolation explained pine diversity (table 4). Species diversity increased by $0.30 \pm 0.08\%$ (\pm SE) with each 1% increase in the log number of km² of woodland ($P < 0.0006$) after adjusting for the effect of dis-

tance to the nearest mainland, whereas, species diversity decreased by $0.38 \pm 0.24\%$ (\pm SE) with each 1% increase in log distance to the nearest mainland ($P = 0.12$) after adjusting for the area effect. With the Sierra San José and Big Hatchet outliers removed, the amount of variation in pine diversity that was explained by area and isolation increased somewhat ($R^2 = 0.61$ vs. 0.47) and the effect of isolation became stronger.

Discussion

Biologists have tried to define factors that explain species diversity across the mountain islands of the western United States and assess how habitat area and isolation affect the distribution of population and diversity of communities. Some studies suggest that both factors are important in explaining diversity of montane birds and mammals in the borderlands mountains while other studies indicate habitat is more important than isolation (Gehlbach, 1995).

We found that these two variables, woodland area and distance to the nearest mainland, considered independently, were each good predictors of pine diversity across the mountain islands of the Madrean Archipelago. Maximum elevation was also considered a potential explanatory variable and found to be a significant predictor of pine species diversity (table 2). The relationship between a mountain's peak elevation and its area of woodland that supports pines can be attributed to the "Merriam Effect" (i.e. increase in orographic precipitation and adiabatic cooling with increases in elevation), so the larger the mountain island, the more conifer forest it contains (Gehlbach, 1981). In our study, maximum elevation and woodland area were correlated and essentially measured the same attribute—habitat area and thus population size of pines. Isolation distance explained less variation in pine species diversity than area, but did have some explanatory power even when adjusting for the effect of area (table 4.)

Table 2—Simple Linear Regression model for the effects of habitat area, elevation and distance to the nearest mainland on the diversity of pine species (ln) in all 31 Sky Island mountain ranges in the Madrean Archipelago and with one outlier removed.

Data set	Explanatory variable	R ²	Estimate	SE	P
All data	Area of pine-oak woodland (ln km ²)	0.42	0.34	0.07	<0.0001
	Maximum elevation (ln m)	0.43	3.20	0.69	<0.0001
	Distance to nearest mainland (ln km)	0.19	-0.70	0.27	0.015
Hatchet removed	Distance to nearest mainland (ln km)	0.26	-0.78	0.25	0.004

Table 3—Simple Linear Regression models for the effects of distance to the Colorado Plateau on the diversity of northern pine species (ln) and distance to the Sierra Madre Occidental on the diversity of southern pine species (ln) in all 31 Sky Island mountain ranges in the Madrean Archipelago and with one outlier removed.

Data set	Explanatory variable	R ²	Estimate	SE	P
All data	Distance to Colorado Plateau (ln km)	0.55	-0.93	0.15	<0.0001
	Distance to Sierra Madre (ln km)	0.11	-0.36	0.18	0.065
Hatchet removed	Distance to Sierra Madre (ln km)	0.26	-0.47	0.15	0.004

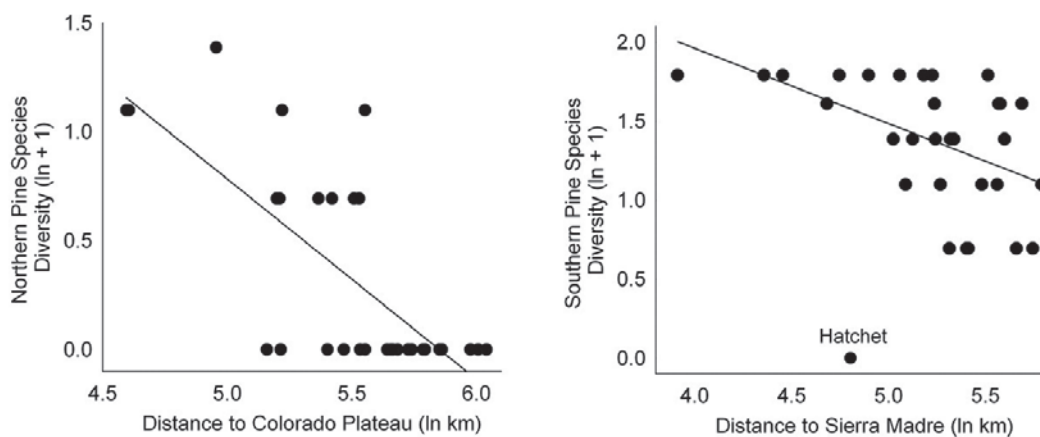


Figure 2—Relationship of pine species diversity (ln) to distance to the Colorado Plateau for northern pine species (left), and distance to the Sierra Madre Occidental for southern pine species (right) in all 31 Sky Island mountain ranges in the Madrean Archipelago. The regression line is the estimate of diversity for each effect. An outlier for the effect of distance on the diversity of southern pines is the Big Hatchet Mountains.

Table 4—Multiple Linear Regression model for the effects of habitat area and distance to the nearest mainland on the diversity of pine species (ln) in all 31 Sky Island mountain ranges in the Madrean Archipelago and with two outliers removed.

Data set	Explanatory variable	Estimate	SE	P
All data (R ² = 0.47)				
	Area of pine-oak woodland (ln km ²)	0.30	0.08	0.0006
	Distance to nearest mainland (ln km)	-0.38	0.24	0.12
Hatchet and San Jose removed (R ² = 0.61)				
	Area of pine-oak woodland (ln km ²)	0.33	0.07	<0.0001
	Distance to nearest mainland (ln km)	-0.38	0.20	0.074

In examining the distribution of reptiles and amphibian species, Swann and others (2005) found that none of the Sky Islands contain a full complement of southern species and that few reptile and amphibian species in the Sky Islands have affinities to areas north of the Sky Islands. For pines, none of the 31 Sky Islands contain a full complement of six southern element species although eight islands have five of the six species, and half of those are in Mexico. All Sky Islands with pines have at least one pine species of southern element in its flora with the exception of the Big Hatchet Mountains. Only one Sky Island has a full compliment of three northern element pine species. Of the 11 Sky Islands that have at least one northern pine species, just one mountain, the Sierra San José, is in Mexico.

An outlier in terms of the effect of distance from the southern mainland on the diversity of pines is the 2540 m high Big Hatchet Mountains. They are positioned close to the southern mainland and support no southern pines species. This could be associated with their longitude as they are at the easternmost edge of the of the Madrean Sky Islands and thus surrounded by the more arid adapted Chihuahuan desertscrub that is east of the Continental Divide, and the only high Sky Island composed entirely of limestone. The Florida Mountains

and Cooke’s Range farther east are not limestone, but also have the same single northern element pine species in their flora, *Pinus edulis*. A dispersal corridor may be to the north along the Continental Divide rather than to the SMO, despite a stepping stone in the adjacent Animas Mountains, which supports five southern pines. On floristic grounds, Big Hatchet is outside of the Apachian floristic subprovince (McLaughlin 1995, 2008).

An outlier in terms of the effect of woodland area on pine species diversity is the 2520 m Sierra San José, which has much higher diversity than expected given its small area. This pattern may be partly explained by latitude. Sierra San José is the second highest in elevation and the farthest north of any Sky Island in Mexico, but its mountain mass (ca. 1 km² above 2300 m) and corresponding woodland area are small. In addition, it is relatively close to two higher mountains (Huachuca Mountains in the United States, and Sierra de los Ajos, the highest island in Mexico) that may act as potential source populations of pines. Birds are known to disperse the seeds of certain pines species and two species that have been found in the San José, *Pinus discolor* and *P. strobiformis* belong to the strobi and cembroides groups of pines that have large and wingless seeds potentially dispersed by birds

(Lanner 1998). Our recent fieldwork, however, failed to document *P. strobiformis* (or *P. chihuahuana*) in the San José that were originally found in 1893 by Mearns (1907; specimens examined by us). These species may now be locally extirpated due to greater susceptibility of small populations to stochastic extinctions as a continuing process, i.e. the few *P. strobiformis* individuals Mearns found near the summit removed by fire.

Varying adaptive strategies of Sky Island pines might explain their present distributions. One pine of the CP-RM element continues across the Sky Islands into the northern SMO, *Pinus ponderosa* var. *scopulorum*; it belongs to a widespread and adaptable “ponderosae” complex with varieties (and species) that range from British Columbia to central Mexico. Pleistocene and early Holocene records are only in Arizona; its range expanded northward during the last 8000 years just as another northern element *P. edulis* did from refugia in the southwestern United States (Lanner and Van Devender 1998). Two pines of the Madrean element that range across 23 Sky Islands and reach the edge of the Colorado Plateau can survive at lower elevations—*P. discolor* as low as 1150 m, and *P. chihuahuana*, on the fringe of the Sky Islands as low as 1310 m—and exhibit better drought tolerance than other pines. *P. engelmannii* is the dominant pine in the SMO, but also occurs on the edge of the SMO and in lower Sky Islands where populations are small, yet does not occur into the northern Sky Islands. *P. arizonica*, widespread in the higher SMO, mostly occurs on mesic N-facing slopes, or canyon bottoms of the higher Sky Islands including the highest northern ones. *P. strobiformis*, the most widespread and highest elevation of any Madrean element pine in the Southwestern United States, is potentially bird-dispersed (by corvids and thick-billed parrots). The northernmost populations of *P. yecorensis* in the Sierra Bacadéhuachi, and adjacent Sierra Huachinera of the SMO, are small and perhaps cold limited; farther south the species is more widespread on the lower Pacific slope of the SMO and borders Tropical Deciduous Forest around latitude 28°N.

None of the *Pinus* in the Madrean Sky Islands of Mexico or the United States have any federal or state conservation status, although limited protected areas exist as reserves (e.g. Ajos-Bavispe, Ramsey Canyon, Saguaro National Park), have controlled access (e.g. Animas Mountains, private), or are managed by the U.S. Forest Service. Disturbance events have altered pine forests at large scales across the Sky Islands (increased fires associated with human activities, insect outbreaks and drought). In smaller ranges where pines occur in tiny isolated populations, these disturbance events are affecting pine diversity and distribution, e.g., a tiny population of *P. engelmannii* on privately managed land in the Sierra San Antonio may have less than 20 individuals at present, with many recent snags that have succumbed to drought in the past 10 years. Similarly, *Pinus engelmannii* in the Sierra Cíbuta, the westernmost outpost for pines in the Sky Islands of Sonora, are in serious decline and many patches of pines have been lost in the last decade. Although marked as present on our list, such pines can be rare, e.g. only a single *P. edulis* was recorded from the Pinaleño Mountains (Jim Malusa, personal observation 1985). Other areas may be under sampled, or less explored, such as in Sierra Enmedio, Chihuahua, where no collections exist for a high mountain bound to support at least one pine species, and in the Dragoon Mountains, Arizona, with only one pine species recorded. The spread of some introduced pines should also be monitored, such as the Eurasian *Pinus sylvestris* that is locally introduced on private lands in the Sierra de los Ajos, Sonora. Given threats to small isolated populations on mountain tops and a rapidly warming and drying climate in the region, efforts to document and monitor the distribution and spatial extent of pine forests across the Sky Islands is critical for conservation.

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Ecosystems and Diversity of the Sierra Madre Occidental

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Abstract—The Sierra Madre Occidental (SMO) is the largest continuous ignimbrite plate on Earth. Despite its high biological and cultural diversity and enormous environmental and economical importance, it is yet not well known. We describe the vegetation and present a preliminary regionalization based on physiographic, climatic, and floristic criteria. A confluence of three main ecoregions in the area corresponds with three ecosystems: Temperate Sierras (Madrean), Semi-Arid Highlands (Madrean Xerophyllous) and Tropical Dry Forests (Tropical). The Madrean region harbors five major vegetation types: pine forests, mixed conifer forests, pine-oak forests, oak forests and temperate mesophytic forests. The Madrean Xerophyllous region has oak or pine-oak woodlands and evergreen juniper scrub with transitions toward the grassland and xerophyllous scrub areas of the Mexican high plateau. The Tropical ecosystem, not discussed here, includes tropical deciduous forests and subtropical scrub. Besides fragmentation and deforestation resulting from anthropogenic activities, other dramatic changes are occurring in the SMO, including damage caused by bark beetles (*Dendroctonus*) in extensive areas, particularly in drought-stressed forests, as well as the expansion of chaparral and *Dodoneaea* scrub at the expense of temperate forest and woodlands. Comments on how these effects are being addressed are made.

Introduction

The Sierra Madre Occidental (SMO) or Western Sierra Madre is the longest mountain range in Mexico and the largest continuous ignimbrite plate on Earth. It has a surface of 251,648 km² (not including the Madrean Archipelago), about the size of the State of Wyoming and even larger than the United Kingdom. Elevations range from 300 to 3340 m. With a rugged physiography of highland plateaus and deeply cut canyons, it extends more than 1160 km from near the United States-Mexico border (30° 35'N) to northern Jalisco (21°00'N) in western Mexico. It is linked to the Rocky Mountains through the Sky Islands in the north and connected with the Trans-volcanic Belt to the south. It is a boundary area for hundreds of species that reach their northern or southern range limits; it also contains a high proportion of endemic elements. The SMO is the source of environmental services for a large area in northwestern and north-central Mexico, includes about two thirds of the standing timber in Mexico, and boasts some of the richest diversity of habitats and species anywhere in North America.

The prominence of the SMO in the biological diversity of Mexico has been addressed by Bye (1995), González-Elizondo (1997), Felger and Wilson (1995), Felger and others (1997), and Van Devender and Reina (2005), among others. Two areas have been recognized by the International Union for the Conservation of Nature (IUCN)

as megacenters of plant diversity: northern Sierra Madre Occidental and the Madrean Archipelago (Felger and others 1997) and the Upper Mezquital River region (González-Elizondo 1997). Its high diversity has been noted by Spellenberg and others (1996) who found 823 plant species for the Cascada de Basaseachi National Park. Felger and others (1997) estimated 4000 species of vascular plants for the northern portion of the range, Martin and others (1998) reported more than 2800 species for the Rio Mayo region, and Vázquez-García and others (2004) listed 2081 species for the Huichol region in the south.

A study on bats (Torres-Morales and others 2010) revealed that species richness of the SMO in northwestern Durango (including temperate and tropical areas) is comparable to that of the tropical rain forests of southeastern Mexico as a result of the great diversity of habitats in relatively small areas. This exceptional diversity is mirrored by three physiognomically dominant Madrean genera: *Pinus*, with 24 species (46% of the Mexican total), *Quercus* with 54 species (34%) and *Arbutus* with 7 species (100%) (González-Elizondo and others, in review). Many new Madrean taxa have been described from the region during the last 10 years, including one genus (González-Elizondo and others 2002) and more than 20 additional species, suggesting that numerous undescribed taxa are still to be found. The recent discovery of a second population for *Pinus maximartinezii* (González-Elizondo and others 2011) after almost 5 decades since its description reveals the probability of deep gaps in knowledge of biodiversity in the SMO.

Studies on SMO ecosystems and its surrounding areas started in the 1940s and continue to date (Spellenberg and others 1998; Van Devender and others 2003; Martínez-Yrizar and others 2010; and papers cited above). However, the Sierra Madre Occidental is far from being biologically and ecologically well known. We present here an outline of the main Madrean vegetation types and a preliminary delimitation of ecoregions of the SMO based on physiographic, climatic, and floristic criteria. Vegetation was mapped using ArcGis 9.3 based

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on the vegetation and land use map data in vector format Series III of INEGI (2002), with adaptations based on field and literature data. This delimitation helps to understand how organisms are distributed in the SMO; as important, it should be a baseline for future studies on taxonomy, biogeography, and ecology.

Results and Discussion

Ecoregions

Three main ecoregions converge in the SMO: Temperate Sierras, Semi-Arid Highlands, and Tropical Dry Forests (CEC 1997). We refer to them as Madrean, Madrean Xerophyllous, and Tropical in the study area.

M—Madrean region occurs on the higher areas of the sierra, following the Continental “backbone,” including highland ridges and a highland plateau (fig. 1 M). It is almost 200 km wide in some places, its climates are temperate and semi-cold, and its prevalent communities are temperate forests in which several conifers and oaks are dominant elements.

MX—Madrean Xerophyllous region occupies the eastern foothills and northern and eastern branches of the cordillera (fig. 1 MX), with semidry temperate or semidry semicold climates. Oak or pine-oak woodlands and evergreen scrub are the dominant vegetation.

T—Tropical region enters the SMO through the tributary ravines on the steep western flanks that drop to the narrow Pacific coastal plain (fig. 1 T). Climates are warm, semi-warm, and dry-warm, with a prevalence of tropical deciduous forests and subtropical scrub.

Two subregions are recognized based on physiographic and floristic criteria within the Madrean region:

M—Madrean *sensu stricto* on the highland ridges and the highland plateau.

MT—Madrean-Tropical on the upper western slopes in which the climates are still temperate but moister and warmer than on the interior of the range. This subregion is recognized by the presence of conifer and oak species with strong affinities to the south, as *Pinus oocarpa*, *P. douglasiana*, *P. devoniana*, *P. luzmariae*, *P. maximoi*, *P. praetermissa*, *P. yecorensis*, *Quercus candicans*, *Q. scytophylla*, *Q. subspathulata*, and *Juniperus flaccida*, among others.

The Madrean *sensu stricto* region can be further divided into Northern, Central and Southern ranges (fig. 1):

M1—The Northern range includes eastern Sonora and western Chihuahua south to the Urique barranca (between 27° and 28° N). With a mean elevation of 2350 m, it has colder and more continental climates than the rest of the SMO. Besides the species shared with the Madrean Archipelago to the north (e.g. *Juniperus scopulorum*, *Quercus gambelii*), *Pinus yecorensis* and *Vaccinium chihuahuense* are characteristic of the zone.

M2—The Central range extends from southwestern Chihuahua to southern Durango and eastern Sinaloa, ending with the Quebrada del río Mezquital (22°50′–23°25′ N). With a mean elevation is 2650 m, it includes peaks above 3200 m. Many species and a genus (*Megacorax*) are restricted here.

M3—The Southern range includes the area from the Río Mezquital to northern Jalisco. It is a rugged zone with deep and wide canyons through which the tropical and xerophyllous zones converge. Many species are restricted to the area, e.g., *Pinus maximartinezii*. An example of the diversity and distribution of plant species by regions is given with *Arbutus* and *Agave* (table 1).

Because barriers to distribution across the tropical region are low, most tropical elements are distributed on a SE to NW continuum along the western foothills of the SMO from northern Nayarit and Jalisco to Sonora and Chihuahua. Nevertheless, some elements are evolving more locally, such as *Agave*, which show differential distributions with some species restricted to the subregions here proposed (table 1). As for *Arbutus*, the SMO harbors the highest diversity worldwide, with seven Madrean species. *Arbutus arizonica* is widely distributed and but other species are restricted to some subregions.

Vegetation

The Madrean, Madrean Xerophyllous and Tropical regions include characteristic ecosystems and vegetation. The Madrean region harbors five major types: pine forests, mixed conifer forests, pine-oak forests, oak forests, and temperate mesophytic forests as well as communities of primary and secondary chaparral and montane meadow vegetation. Madrean Xerophyllous includes oak or pine-oak woodland and evergreen juniper scrub with transitions toward the grassland and xerophyllous scrub of the Mexican high plateau and to the subtropical scrub at the southern area of the Madrean Archipelago subregion. A map (fig. 2) illustrates the Madrean and Madrean Xerophyllous vegetation types. The Tropical region has a prevalence of tropical deciduous forests and subtropical scrub, with small spots of tropical subdeciduous forest. These three, with no Madrean affinities, are not treated here. They would occupy the ravines on the western and southern flanks of the sierra in the map.

The classification of the vegetation follows Rzedowski (1978), a system of basic and excluding categories that is (1) easy to subcategorize and adapt to more specific situations; (2) comparable with other systems worldwide; and (3) relatively easy to map. The system combines physiognomic, floristic and ecological criteria.

Pine Forests

Between 1600 and 3320 m, these forests cover 12% of the surface area in diverse combinations of *Pinus*. They occur in several environmental conditions, with combinations of mainly *P. arizonica*, *P. engelmannii*, and *P. chihuahuana* on the northern and central zones of the range; *P. durangensis* or *P. teocote* from central Chihuahua to the south; and *P. leiophylla* and *P. strobiformis* in humid sites. *P. cooperi* is monodominant in valleys with deep soils, while the weeping pine (*P. lumholtzii*) dominates thin, acidic, poor soils. On the western slopes (region MT), *P. oocarpa*, *P. yecorensis*, *P. douglasiana*, *P. herrerae*, *P. devoniana*, and *P. maximoi* dominate in subhumid places, *P. lumholtzii* or *P. luzmariae* on poor soils.

Mixed Conifer Forests

Fir and pine-fir forests cover less than 0.3% of the surface area mainly in small patches between 1900 and 3300 m in humid ravines and slopes in the north. The physiognomic dominants are Douglas-fir (*Pseudotsuga menziesii*) and species of *Abies* and *Picea* associated with *Pinus* and sometimes *Quercus*. *Pseudotsuga* predominates, but there are also small areas of *Abies durangensis* and *Picea chihuahuana*, and even smaller areas of *Abies concolor*, *A. neodurangensis*, and *Picea engelmannii* var. *mexicana*.

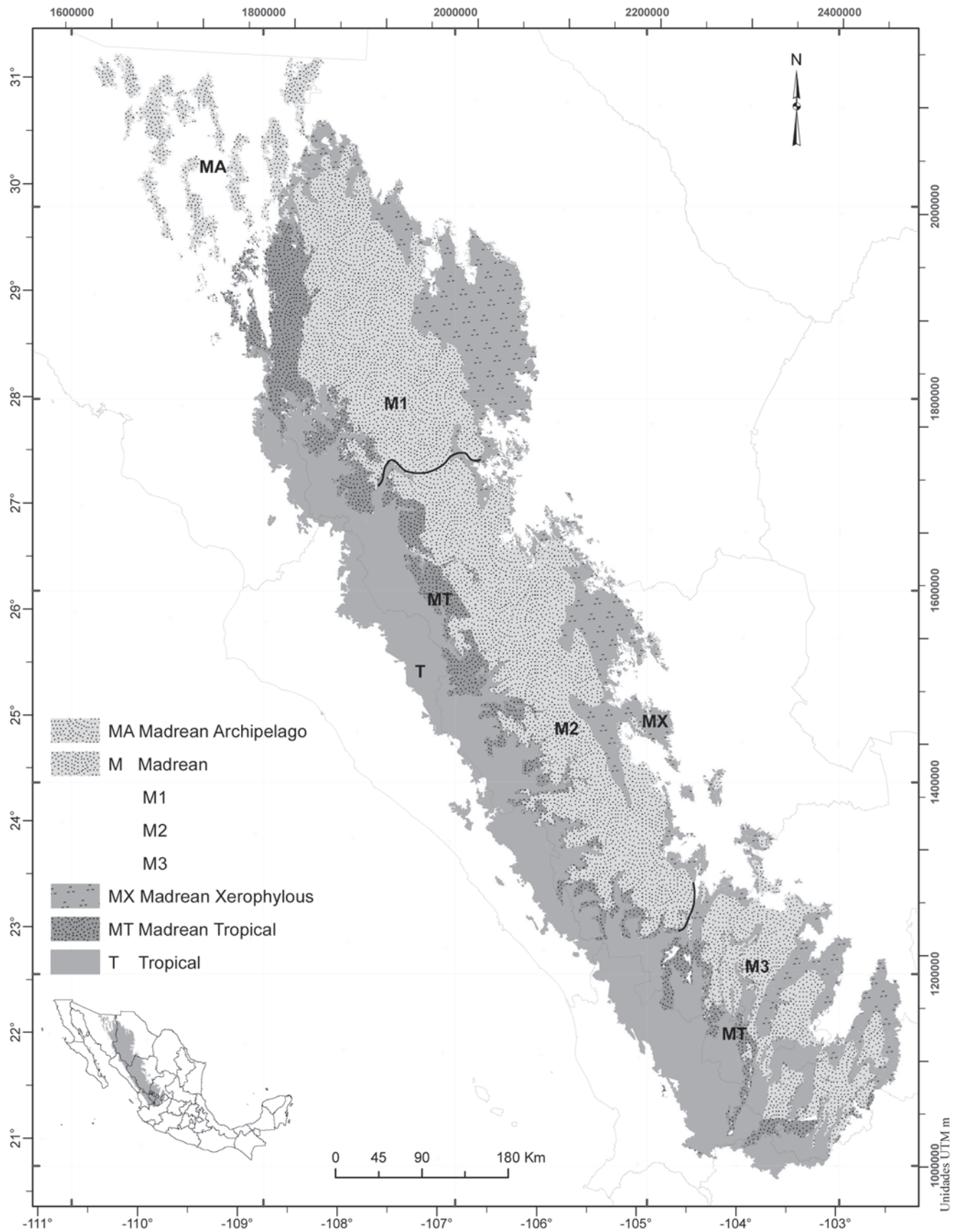


Figure 1—Regions and subregions of the Sierra Madre Occidental. MA = Madrean Archipelago; M = Madrean; MX = Madrean Xerophyllous; MT = Madrean with tropical affinities; T = Tropical; M1 = North; M2 = Center; M3 = South.

Table 1 --Species of *Agave* and *Arbutus* in the Sierra Madre Occidental.

Species	MA	M1	M2	M3	MX1	MX2	MX3	MT1	MT2	MT3	T1	T2	T3
<i>Arbutus arizonica</i> (A. Gray) Sarg.	1	1	1	1									
<i>A. bicolor</i> S. González, M. González et P.D. Sorensen		1	1	1									
<i>A. madrensis</i> S. González			1	1									
<i>A. mollis</i> HBK.				1									
<i>A. occidentalis</i> McVaugh & Rosatti			1	1									
<i>A. tessellata</i> P.D. Sorensen								1	1	1			
<i>A. tessellata</i> P.D. Sorensen f. <i>repens</i>			1										
<i>A. xalapensis</i> HBK. var. <i>texana</i> (Buckley) A. Gray	1												
<i>A. xalapensis</i> HBK. var. <i>xalapensis</i>								1	1	1			
<i>A. xalapensis</i> HBK. f. <i>glandulosa</i> M. Martens & Galeotti													
<i>Agave angustifolia</i> Haw. var. <i>angustifolia</i>								1	1	1			
<i>A. angustifolia</i> Haw. var. <i>rubescens</i> (Salm-Dyck) Gentry									1	1			
<i>A. applanata</i> Lem. ex Jacobi						1							
<i>A. attenuata</i> Salm-Dyck subsp. <i>pedunculifera</i> (Trel.) B. Ullrich									1	1			
<i>A. bovicornuta</i> Gentry								1	1	1			
<i>A. chrysoglossa</i> I.M. Johnst.											1		
<i>A. durangensis</i> Gentry						1			1	1			
<i>A. filifera</i> Salm-Dyck subsp. <i>microceps</i> Kimmach									1	1			1
<i>A. filifera</i> Salm-Dyck subsp. <i>multifilifera</i> (Gentry) B. Ullrich									1	1			
<i>A. filifera</i> Salm-Dyck subsp. <i>schidigera</i> (Lem.) B. Ullrich	1		1	1									
<i>A. flexispina</i> Trel.						1							
<i>A. geminiflora</i> (Tagl.) Ker-Gawler											1		
<i>A. guadalajarana</i> Gentry											1		
<i>A. impressa</i> Gentry												1	1
<i>A. inaequidens</i> K. Koch subsp. <i>barrancensis</i> Gentry										1			
<i>A. jaiboli</i> Gentry								1					
<i>A. maximiliana</i> Baker var. <i>katharinae</i> (A. Berger) Gentry			1						1	1			
<i>A. maximiliana</i> Baker var. <i>maximiliana</i>			1	1					1	1			1
<i>A. nayaritensis</i> Gentry									1	1			
<i>A. ocahui</i> Gentry var. <i>ocahui</i>													
<i>A. ocahui</i> Gentry var. <i>longifolia</i> Gentry								1	1	1			
<i>A. palmeri</i> Engelm.													
<i>Agave parryi</i> Engelm. var. <i>huachuensis</i> (Baker) Little	1					1							
<i>A. parryi</i> Engelm. subsp. <i>neomexicana</i> (Wootton & Standley) B. Ullrich								1	1	1			

Table 1—Continued.

<i>A. parryi</i> Engelm. var. <i>parryi</i>							1	1																
<i>A. parryi</i> Engelm. var. <i>truncata</i> Gentry								1																
<i>A. parviflora</i> Torr. subsp. <i>densiflora</i> G. Starr & T.R. Van Devender							1																	
<i>A. parviflora</i> Torr. subsp. <i>flexiflora</i>							1																	
<i>A. parviflora</i> Torr. subsp. <i>parviflora</i>							1																	
<i>A. pinitilla</i> S. González, M. González y L. Reséndiz										1														
<i>A. polianthiflora</i> Gentry										1														
<i>A. potrerana</i> Trel.										1														
<i>A. rhodacantha</i> Trel.																					1	1	1	
<i>A. rzedowskiana</i> P. Carrillo, R. Vega & R. Delgad.																					1	1		
<i>A. salmiana</i> Otto ex Salm-Dyck subsp. <i>crassispina</i> (Trel.) Gentry																								
<i>A. schottii</i> Engelm.							1																	
<i>A. shrevei</i> Gentry subsp. <i>magna</i> Gentry																					1	1		
<i>A. shrevei</i> Gentry subsp. <i>matapensis</i> Gentry																						1		
<i>A. shrevei</i> Gentry subsp. <i>shrevei</i>																					1	1		
<i>A. striata</i> Zucc. subsp. <i>falcata</i> (Engelm.) Gentry																								
<i>A. vilmoriniana</i> Berger																						1	1	1
<i>A. wocomahi</i> Gentry								1														1	1	
<i>Agave</i> sp. nov. 1																							1	

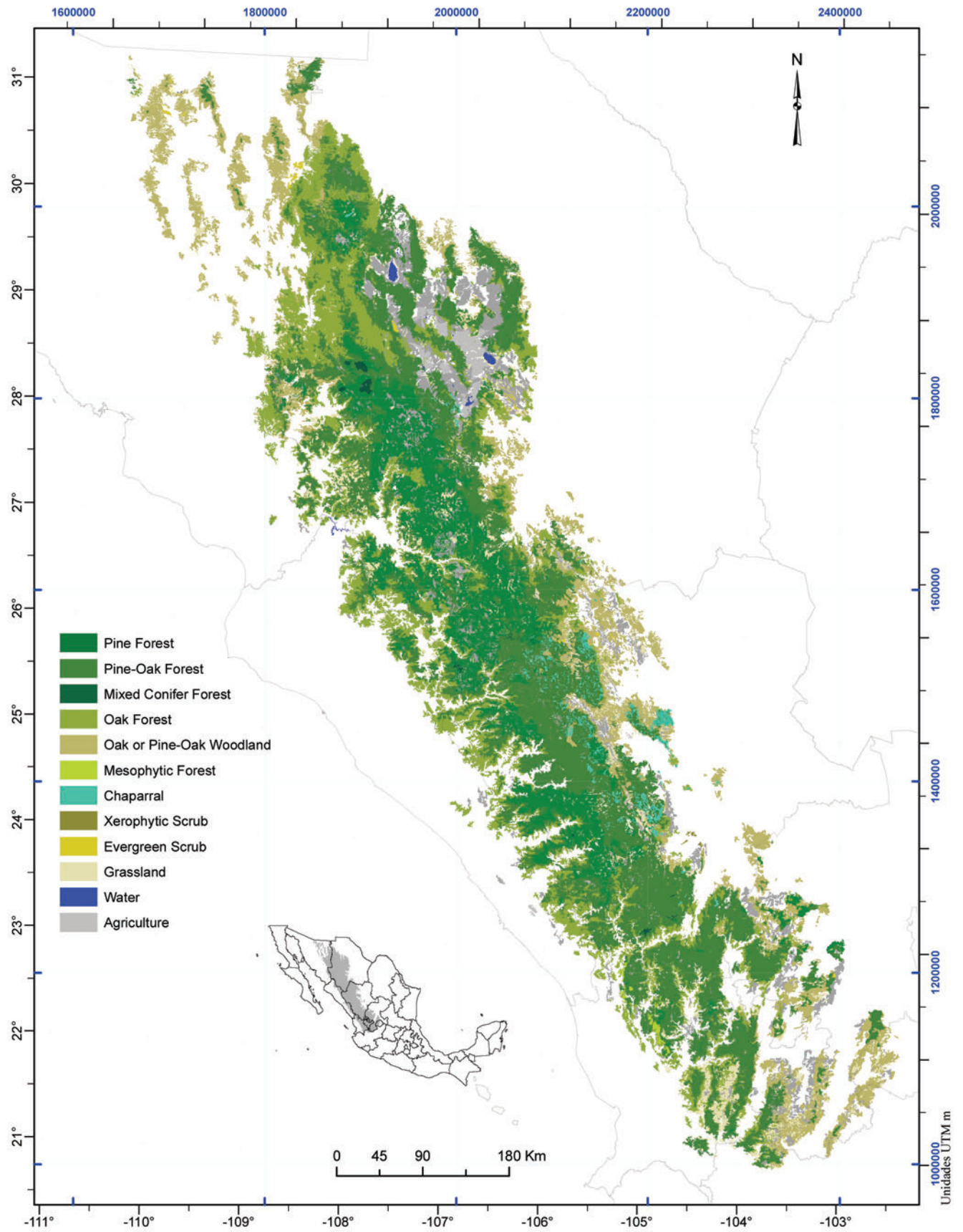


Figure 2—Vegetation of the Sierra Madre Occidental.

Pine-Oak Forests

Covering about 30% of the surface, from 1250 to 3200 m, pine-oak forests occur with a wide array of species combinations depending on elevation, physiography, and climate: *Pinus arizonica*, *P. engelmannii*, and *P. chihuahuana* with *Quercus rugosa* and/or *Q. gambelii* in the northern portions of the SMO; *P. durangensis*, *P. teocote*, and *P. cooperi* with *Q. sideroxylla*, *Q. crassifolia*, *Q. rugosa*, *Arbutus bicolor*, *A. madrensis*, and *A. arizonica* in relatively dry places; or *A. tessellata* in warmer areas. Diverse species of *Quercus* may combine with *P. engelmannii*, *P. chihuahuana*, and *A. arizonica* in semi-dry temperate areas. On thin soil or outcrops of very unsheltered bedrock, forests of *P. lumholtzii* with *Q. radiata* and a xeric phase of *Q. crassifolia* are prominent. Manzanita (*Arctostaphylos pungens*), *Juniperus deppeana*, and *J. durangensis* are among the common shrubs. On the western slopes (MT), *P. oocarpa* is associated with *P. devoniana*, *P. douglasiana*, *Q. viminea*, and *Q. gentryi*, among others. *Pinus herrerae* dominates on ridges and slopes while on lower areas *P. luzmariae* is on mesas and hillsides frequently with *P. lumholtzii* and *Q. radiata*. Between 1800–2300 m, *Q. jonesii* mixes with *P. lumholtzii*, *Q. resinosa*, *Q. crassifolia*, and *Q. viminea*. *Q. resinosa* mixes with *Q. praineana* and *P. oocarpa* on lower elevations in Durango, Jalisco, and Zacatecas.

Oak Forests

These forests are communities with a dominance of *Quercus* species but with very different composition, structure, and ecological affinities. They cover almost 14% of the surface area of the SMO, from 340 m on low hills in the middle of tropical deciduous forest, to 2900 m in semi-cold climates. Communities dominated by *Quercus* in dry temperate climates are described under the oak woodlands. Among the main associations are *Q. sideroxylla* and *Q. rugosa*, up to 2900 m and *Q. fulva*, *Q. mcvaughii* or *Q. scytophylla* below. *Q. laeta* has a broad ecological tolerance, occurring on the western and southern flanks of the SMO. In the Madrean Tropical subregion there are mesophytic oak forests with *Q. candicans*, *Q. crassifolia*, *Q. diversifolia*, *Q. scytophylla*, and *Clethra* spp; at lower elevations, *Q. subspathulata* enters the subregion. Other oak forests on the western flanks are those of *Q. viminea* or *Q. alamosensis* to the north and *Q. diversifolia* and *Q. gentryi*. *Q. albocincta* occurs at lower elevations. In the south, low forests of robles (*Q. magnoliifolia*, *Q. resinosa*) sometimes with *Q. eduardii* or *Q. viminea*, are found in many areas being substituted by *Dodonaea* scrub.

Mesophytic Forests

These forest communities are rich in their diversity and structure. They occupy small areas, covering about 0.14% of the surface area on the western flank of the sierra, between 1000 and 2350 m. Among their characteristic elements are *Magnolia pacifica* subsp. *tarahumara*, *Ostrya virginiana*, *Tilia americana* var. *mexicana*, *Cedrela odorata*, *Styrax ramirezii*, several *Lauraceae* such as *Persea liebmannii*, *P. podadenia*, *Nectandra* spp. and *Litsea* spp and oaks like *Q. candicans*, *Q. crassifolia*, *Q. castanea*, *Q. rugosa*, *Q. scytophylla*, and *Q. splendens*. Other species are *Arbutus xalapensis*, *Garrya laurifolia*, *Cornus disciflora*, *C. excelsa*, *Clethra* spp, *Prunus* spp, *Peltostigma pteleoides*, *Ilex quercetorum*, *I. toluccana*, *Cleyera integrifolia*, and *Brahea aculeata*. Often pines and other conifers are present including *Pinus maximinoi*, *P. devoniana*, *P. douglasiana*, *P. herrerae*, *P. strobiformis*, *P. durangensis*, *Abies neodurangensis* or *Pseudotsuga*

menziesii. Other communities, such as the Madrean montane meadow that occurs in small spots between 2300 and 3100 m, include a high proportion of endemic species.

Oak or Pine-Oak Woodlands

These woodlands cover more than 13% of the surface along the eastern foothills and isolated outlying ranges of the SMO at 1450–2500 m. Physiognomic dominants are pinyon (*Pinus cembroides*) and/or several species of *Quercus* of xerophyllous affinities.

In northern Sonora and Chihuahua, blue oak (*Q. oblongifolia*), Emory oak (*Q. emoryi*), or Arizona oak (*Q. arizonica*) are often monodominant or associated with *Pinus cembroides*, *P. chihuahuana*, *Arbutus arizonica*, *Q. grisea*, and *Q. chihuahuensis*. *Quercus hypoleucoides* occurs in the uplands and to the west is *Q. viminea*. Common associations on the eastern foothills of the sierra are those of *P. cembroides* and *Q. grisea* or *Q. eduardii*. At the transition with higher elevation forests, *Pinus chihuahuensis*, *P. engelmannii*, and *Q. durifolia* are common. Tásate (*Juniperus deppeana*) is the common shrub; *J. coahuilensis* enters the region where lower elevation juniper scrub contacts higher elevation woodlands.

Weaknesses and Strengths of the Present Situation of the Madrean Ecosystems in the Sierra Madre Occidental

An accelerated deforestation, fragmentation of habitats, and reduction in forest densities are the most dramatic changes occurring in the last decades in the Sierra Madre Occidental. Although sustainable forest management is promoted and forest certification has become well established in many ejidos, communities, and private lands, illegal logging still persists as well as clearing of the forest for agriculture or cattle grazing. Forests and woodlands of the SMO have been becoming more open and replaced by shrubs (inland chaparral), a disturbance linked to perturbation by logging, overgrazing, and fire. Also, extreme climatic events in the lower peripheral communities are driving changes. A striking example of this was the heavy frosts of the winter of 1997 that killed extensive areas of *Acacia schaffneri* and *Opuntia* scrub on the areas flanking the eastern foothills. This was followed by an extreme drought and hot temperatures during the 1998 spring that reduced many of the oak woodlands at the eastern lower slopes.

Other changes occurring in the vegetation cover are (1) the expansion of the shrubs *Arctostaphylos pungens* and *Quercus depressipes* driven by disturbance; (2) the dwindling of oak woodlands that are being replaced by hopbush (*Dodonaea viscosa*), an invader from warmer areas; and (3) the effects of bark beetle (*Dendroctonus*) infestation that have killed extensive areas of pines and also affected fir, Douglas-fir and spruce that were likely already stressed by drought.

The implementation of sustainable management in recent years is allowing conservation of the biodiversity in some places of the sierra. CONAFOR's National Forest Commission programs on payment for environmental services (including hydrological, carbon sequestration, and conservation of biodiversity) and protection and conservation of soils, reforestation and watershed restoration involve ejidatarios, comuneros, and private owners in the processes of protection and management of ecosystems. Additionally, many communities are betting on ecotourism, as well as rural and adventure tourism, which represent an alternative to logging and provide time for the forest to recover, bringing hope to the ecosystems and people of the SMO.

Conclusions

Despite its high biological and cultural diversity, the SMO is ironically far from being well known. New records, new species, and new genera are still being discovered in areas of the Sierra Madre Occidental. Much of the biological treasures of this mountain range remain to be discovered and much more exciting exploration is yet to be done to find them.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Wide Ranges of Functional Traits in the Flora from the Central Region of Sonora: A Diversity to be Explored

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Abstract—Although the Sonoran Desert does not have the highest plant species richness, it has been documented with the highest growth form diversity from the North American deserts. It is not known if this high growth form diversity could also harbor a high functional diversity. In this study we characterize the ecophysiological functional traits of photosynthetic capacity, stomatal conductance, transpiration and resource use efficiency (water and nitrogen), as well as morphological and structural traits of specific leaf area and nitrogen content in 52 species that inhabit the arid and semiarid Central Region of Sonora. For all species and analyzed traits, we found a larger range of values compared to those reported from a recent world survey, which represent a very high functional diversity. Such large range and amplitude in functional trait values has not been reported for other regions of the world. This study presents evidence of the high functional diversity of the Sonoran Desert plants waiting to be described and documented.

Introduction

Great efforts have been made to know the functional traits of species that inhabit the different biomes of the world during the past two decades. This information is important because it allows us to know and understand the biodiversity, not just from a taxonomic point of view but as functional diversity or, in other words, the functions, properties, and possible effects and responses of the species to the environment. Leaf traits are the most common and important plant functional traits because they are strongly related to various traits of other parts of the plants, to species ecological strategy, and even to various aspects of the ecosystem functioning (Cornwell and others 2008; Craine and others 2005; Díaz and others 2004; Vendramini and others 2002; Westoby 1998).

At a global level, the major effort so far to assess functional traits of plant species is the TRY database (online in <http://try-db.org/>) with over 3 million trait records from 69,000 species from all major biomes in the world. Kattge and others (2011) suggest that it is evident that plant traits from the warm deserts and, in general, most of the arid and semiarid zones floras of the world are still poorly represented in this database.

Arid and semiarid zones are important worldwide because they represent almost 50% of the terrestrial area (without considering the polar caps). Shreve (1942) and Stebbins (1952) recognized the large growth forms and trait diversity that existed in the plants from these ecosystems and the different ways in which they deal with extreme

conditions of water scarcity, high temperatures, and high irradiance that characterize them. This can mean that arid and semiarid zones harbor a high functional diversity; however, this issue has been little explored.

The Sonoran Desert, as delimited by Shreve and Wiggins (1964), shows some climatic and floristic particularities compared to other deserts of the world. It possesses a bi-seasonal rainfall pattern for most of its extension, with abundant monsoon rains in summer and long duration and highly unpredictable low intensity rains during winter (Brito-Castillo and others 2010; Shreve and Wiggins, 1964; Schmidt 1989). Its flora has nearctic and neotropical biogeographic influences (Castellanos 1992), which result in a great number of species that reach its most northern, southern, or western distribution limits in this region (Castellanos 1992; Castellanos and others 2010; Van Deventer and others 2010). In the Central Region of Sonora, however, its major affinity is with the highly seasonal neotropical flora from the tropical deciduous forest ecosystems of Mexico (Rzedowski, 1973). Moreover, it has been found that the Sonoran Desert possesses the highest growth form diversity of the North American deserts (Shreve 1942; Cody 1991).

Due to the poor representation of warm deserts in plant functional trait studies, and to the climatic and floristic particularities above mentioned of the Sonoran Desert, the objective of this research was to conduct a characterization of leaf traits of species that inhabit the arid and semiarid area of the Central Region of Sonora. We assessed these through a large sampling in terms of number of species, growth forms, habitats, and habits. It is in this Central Region of Sonora, which comprises a gradient of arid and semiarid zones, where desert and subtropical vegetation integrates in ecotones creating interesting mosaics in terms of biota composition and physiognomy of plant communities.

The large sampling undertaken in this study was conducted where both “soft” leaf traits as the specific leaf area, leaf nitrogen content, and “hard” as various ecophysiological traits related to the photosynthesis and gas exchange were considered (Lavorel and Garnier, 2002)

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

to represent the functional diversity of the flora from this region in a variety of leaf traits. It was expected that the species would show wide ranges in the leaf traits due to the great variety of strategies and traits of plants that inhabit these environments can develop to deal with the extreme conditions in the arid and semiarid zones, as suggested in Stebbins (1952).

Methodology

Study Sites

To include the more representative plant communities from the Central Region of Sonora, 14 localities were selected following a gradient in vegetation, aridity and disturbance level (table 1). These sites were located near the limits of the Plains of Sonora and Foothills Thornscrub subdivisions of the Sonoran Desert (Shreve and Wiggins 1964).

Species Leaf Traits Characterization

Samplings in the 14 sites were carried out in September and the first half of October in 2010 to determine some species leaf traits. An effort was made to include a wide variety of species, growth forms, habitats, and habits. The sampling period was in the rainy season to avoid the limiting effects of the water stress on the photosynthetic capacity with measurements made between the 8:00 AM and 12:00 PM.

On each site and for each species, photosynthesis of leaves at high irradiances (generally 1500–2000 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$) was determined at field natural conditions as a measure of the photosynthetic capacity (A_{area}), stomatal conductance to water vapor (g_s), transpiration rate (E), water use efficiency ($\text{EUA} = \text{Amount of fixed CO}_2 \text{ per unit of transpired water}$), and intercellular concentration of CO_2 using a portable photosynthesis system LCI (ADC BioScientific, England) provided with the broad leaf chamber. Also, the dark respiration rate (R) was determined for some species by putting the leaves in complete darkness during the measurement period. At least three plants per species were measured, one leaf per plant, with three measurements per leaf, except in rare occasions where it was not possible to sample enough individuals. Each measured leaf was collected in paper envelopes and stored in ice for its transportation. The real area used in

the measurements of gas exchange was determined using the image analyzing software ImageJ 1.43u (National Institutes of Health, USA). This value was used to correct the gas exchange measurements.

After the measurement of leaf area, each leaf was oven-dried at 70 °C for 2 days to determine leaf dry weight. Using the leaf area and dry weight, the specific leaf area (SLA) was calculated. For those same leaves, nitrogen content per leaf weight (N_{mass}) was determined by the fenate method for Kjeldahl total nitrogen using a Digester 2020 (Tecator, Spain) and a rapid flow analyzer RFA (ALPKEM). The measure of specific leaf area was used as a conversion unit for expressing some leaf traits on a mass and area basis (mass and area subscripts). The nitrogen use efficiency was calculated for each measure of A_{area} as the $A_{\text{area}}/N_{\text{area}}$ quotient. The complete list of leaf traits measured and their corresponding units are listed in the table 2.

Data Analysis

All the data were screened and those that showed any evidence of stress limitation weren't included in the analysis (e.g., stomatal conductance values below 0.05 $\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$ (Flexas and others 2006) or individual trait values far from the trend of the rest of the values for the same species). A mean value for each measured leaf trait was obtained with the remaining data for each species. These mean values are those reported in the paper and compared with all of the world data (TRY database in Kattage and others 2011).

Results and Discussion

Leaf Traits of Species in the Central Region of Sonora

A total of 52 species was sampled that represent a wide variety of growth forms (with the exception of plants with CAM photosynthetic pathway) including those species that are the most commonly found in the flora of the Central Region of Sonora. All species were sampled under natural conditions except for *Cucurbita digitata*, *C. palmeri*, *Jatropha cinerea* and the exotic ruderal *Ricinus communis*, which were sampled under irrigated conditions. Photosynthesis and gas exchange data were obtained for 51 species. Only *Ipomoea nil*

Table 1—Geographic location, vegetation type, and annual rainfall for the study sites.

Site	Latitude	Longitude	Vegetation type ^a	Annual rainfall ^b
1	N 29.023°	O 111.137°	Abandoned agricultural field	200-300 mm
2	N 28.966°	O 110.961°	Subtropical scrub	200-300 mm
3	N 28.700°	O 110.540°	Subtropical scrub	400-500 mm
4	N 28.710°	O 110.540°	Induced buffel savanna	400-500 mm
5	N 29.563°	O 111.011°	Disturbed mezquital	300-400 mm
6	N 29.684°	O 110.145°	Disturbed mezquital	500-600 mm
7	N 29.559°	O 110.123°	Disturbed mezquital	500-600 mm
8	N 29.474°	O 110.217°	Subtropical scrub	500-600 mm
9	N 29.465°	O 110.248°	Subtropical scrub	500-600 mm
10	N 29.439°	O 110.315°	Riparian vegetation	400-500 mm
11	N 29.435°	O 110.334°	Mezquital	500-600 mm
12	N 29.346°	O 110.497°	Desert microphyllous scrub	400-500 mm
13	N 29.327°	O 110.561°	Riparian vegetation	400-500 mm
14	N 29.240°	O 110.726°	Mezquital	300-400 mm

^aFollowing the INEGI's land use and vegetation classification for Mexico

^bFollowing the isohyets map of Mexico by CONABIO. Online at: <http://www.conabio.gob.mx/informacion/gis/>

Table 2—Leaf traits characterized for the species, its abbreviations and measurement units.

Leaf trait	Abbreviation	Units
Specific leaf area	SLA	m ² kg ⁻¹
Photosynthetic capacity per leaf area	A _{area}	μmol CO ₂ m ⁻² s ⁻¹
Photosynthetic capacity per leaf dry mass	A _{mass}	nmol CO ₂ g ⁻¹ s ⁻¹
Transpiration rate	E	mmol H ₂ O m ⁻² s ⁻¹
Stomatal conductance to water vapor	g _s	mol H ₂ O m ⁻² s ⁻¹
Dark respiration per leaf area	R _{area}	μmol CO ₂ m ⁻² s ⁻¹
Dark respiration per leaf dry mass	R _{mass}	nmol CO ₂ g ⁻¹ s ⁻¹
Leaf nitrogen content per leaf area	N _{area}	g N m ⁻²
Leaf nitrogen content per leaf dry mass	N _{mass}	%
Nitrogen use efficiency	NUE	μmol CO ₂ g ⁻¹ N s ⁻¹
Water use efficiency	WUE	μmol CO ₂ mmol ⁻¹ H ₂ O

did not give reliable data because plants were under stress. However, its leaves were included in the data for specific leaf area (SLA) and nitrogen content (N). Data were obtained on dark respiration (R) for 21 species. The SLA could be determined for all the species, while N and nitrogen use efficiency (NUE) could be determined for 48 and 46 species respectively. Compared to previous data (Wright and others 2004; Kattge and others 2011), this study had the largest number of species with an ecophysiological characterization from an arid or semiarid region and from the Sonoran Desert.

Trait mean values for all species grouped by growth form are shown in table 3. Evergreen trees presented the lowest values of gas exchange and SLA traits, herbaceous and grass species had the highest gas exchange values, vines had the highest SLA and high A_{mass}, N_{mass} and g_s but low A_{area}, and shrubs had intermediate values on all traits. These patterns had the most traits that agree with previously reported values for these groups of plants (Larcher 1995; Castellanos 1991; Castellanos and others 1989).

Comparison of Leaf Traits From Species of the Central Region of Sonora with Those of the World

Several studies have addressed the issue of the leaf functional traits of species in different biomes of the world and, therefore, may serve to give a meaning to the values found in the species of the Central Region of Sonora. For example, the mean values of SLA and N of the species of the present study (fig. 1) agreed with values reported for species with the lowest leaf life spans (between 1-4 months) (Reich and others 1992; 1997), which may be related to the short seasonal character of species in the Central Region of Sonora. These values may be considered high in a global context of the species and in particular for those that could be expected in an arid region where the trend for species that inhabit the warmest and driest regions have the lowest SLA (Wright and others 2004) in contrast with our findings in this study. Wright and others (2005) report that species with the highest irradiances and lowest annual rainfall habitat conditions had highest values in N_{area}, which agrees with the high values found in

the studied species, although in this study we also report high values of N_{mass} (fig. 1).

It is evident that all leaf traits from the species that we studied had a similar or larger range of values than those reported for all the species in the world that have been studied (fig. 1) in comparing the data for the species that we studied with those of the global compendium of the TRY database functional traits (Kattge and others 2011). In fact, the maximum value in all the trait ranges exceeds the value of the 97.5% quantile from the data of TRY database. Ranges this wide are not common and we have not found such amplitude in the literature from other ecosystems or regions of the world. According to Tilman's (2001) definition of functional diversity, those components of biodiversity that influence how an ecosystem operates or functions that we found for both ecophysiological and morphostructural traits or "hard" and "soft" traits *sensu* (Lavorel and Garnier 2002) in species that inhabit the arid and semiarid zones of the Central Region of Sonora represent, without any doubt, the high functional diversity that exists in the flora of the southwestern Sonoran Desert.

Previous studies that have documented a high biological diversity different from the taxonomic diversity in the Sonoran Desert are those of Shreve (1942) and more recently Cody (1991, which point out the highest growth form diversity of the North American deserts. Nilsen and others (1984) documented a wide diversity in ecophysiological strategies in water use within a single functional type, the phreatophytes of the Sonoran Desert. Stebbins (1952) explains that the plant diversity in sites with aridity may be high, where an important factor is the high environmental (resources) and topographical heterogeneity, but plants show a wide variety of ways (strategies) and structures (organs) that can make it possible for a plant to inhabit arid conditions, which can be interpreted as a high functional diversity.

A few efforts to understand the causes of high biological and functional diversity of the Sonoran Desert have been reported while a major emphasis has gone to describe its taxonomic diversity (Shreve and Wiggins, 1964; Turner and 1995; Molina and Van Devender 2010). We propose that the high diversity (e.g., functional diversity and growth form diversity) is found in the Central Region of Sonora may be due a number of factors including (1) the floristic affinity, influence and confluence of different contiguous biogeographic (Nearctic and Neotropical) regions (Rzedowski, 1973; Castellanos, 1992; Castellanos

Table 3—Leaf trait mean values per species growth form.^a

Type ^b	Subtype ^b	SLA	N _{mass}	A _{area}	A _{mass}	g _s	WUE	NUE
Trees	Evergreen (3)	9.14 ± 2.05	2.13 ± 0.61	14.42 ± 5.27	129.83 ± 22.88	0.27 ± 0.14	2.09 ± 0.60	5.23 ± 1.25
	Deciduous (6)	15.29 ± 5.16	2.93 ± 0.76	20.99 ± 7.28	292.52 ± 117.59	0.60 ± 0.38	1.79 ± 0.47	10.54 ± 3.54
Shrubs	Deciduous (15)	12.77 ± 2.22	2.99 ± 0.83	22.44 ± 7.90	273.33 ± 106.84	0.69 ± 0.42	1.71 ± 0.51	8.63 ± 4.82
	Ferns (1)	14.01	4.58	19.44	272.38	0.94	0.86	5.94
Herbs	Summer annuals (5)	20.27 ± 10.85	2.35 ± 2.27	36.97 ± 21.49	721.86 ± 585.27	0.72 ± 0.52	2.49 ± 0.47	122.71 ± 186.65
	Perennials (6)	15.57 ± 5.90	2.71 ± 1.29	23.66 ± 14.66	346.87 ± 218.18	0.60 ± 0.43	1.75 ± 0.32	32.43 ± 58.01
	Grasses (6)	18.31 ± 3.71	2.49 ± 1.82	35.05 ± 11.26	603.40 ± 143.60	0.33 ± 0.25	3.21 ± 1.64	53.53 ± 48.74
	Vines (10)	30.86 ± 19.40	3.52 ± 1.24	14.83 ± 6.28	451.06 ± 279.52	0.67 ± 0.47	1.84 ± 0.84	13.52 ± 7.26

^aLow values are underlined, and high values are in bold. Values after the symbol ± are 1 Standard deviation. Units are the same as in table 2.

^bNumbers in parenthesis represent the number of species per growth form.

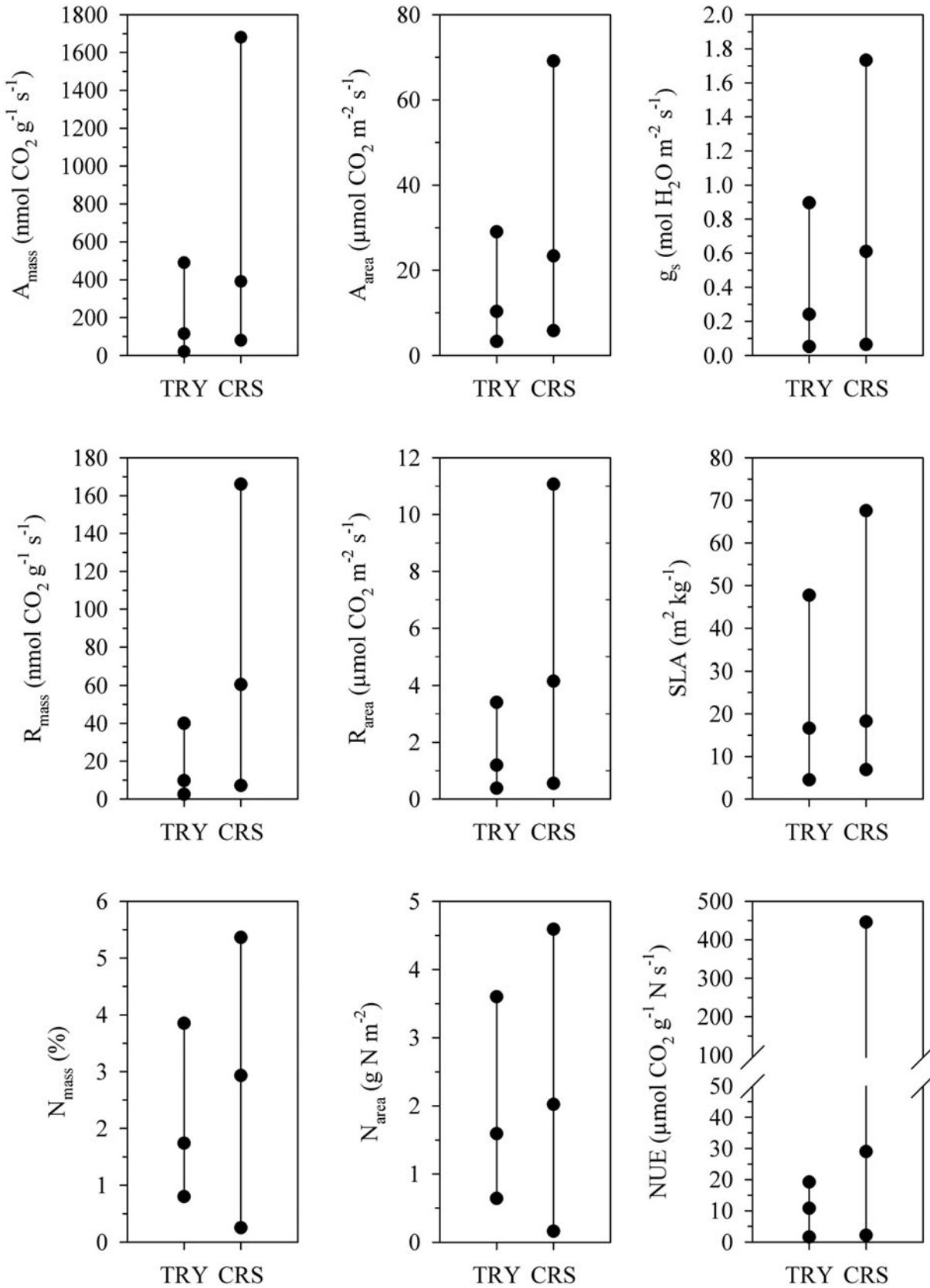


Figure 1—Comparison of leaf trait ranges between the species of the Central Region of Sonora (CRS) and the the world species included in the TRY database (TRY). Data points for the TRY species correspond to the 2.5% quantil (lowest point), mean value (mid point), and 97.5% quantil (highest point), and for the CRS species are the minimum (lowest point), mean (mid point) and maximum values (highest point).

and others 2010; Van Devender, 2010); (2) a large environmental heterogeneity in a short distance (Castellanos and others 1992); and (3) the interspecific positive ecological interactions (e.g., facilitation, nursing, symbiosis, mutualism, fertility islands, etc.) that can allow that species with different ecological strategies and stress tolerance levels to coexist in the same ecosystem.

Conclusions

Ecophysiological and morphostructural leaf traits of 52 species were characterized, which makes this study the largest for the ecophysiological characterization from an arid and semiarid and from the Sonoran Desert species. The ranges found in all leaf traits characterized for the studied species of the Central Region of Sonora had a similar and even larger range of values than those reported for all the species in the world. This wide amplitude in the ranges of leaf trait values is an indicator of a very high functional diversity in the species that inhabit the arid and semiarid gradient of the Central Region of Sonora. This work is evidence of the high functional diversity in the Sonoran Desert plants waiting to be described and documented.

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Cytogeography of *Larrea tridentata* at the Chihuahuan-Sonoran Desert Ecotone

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Abstract—The long separation of the Chihuahuan and Sonoran Deserts is reflected in the high species richness and endemism of their floras. Although many endemic species from both deserts reach their distributional limits where the Sierra Madre Occidental massif fragments into smaller mountain complexes in northern Mexico and adjoining areas of the United States, indicator species approaches to identify the boundary between the Chihuahuan and Sonoran Deserts are complicated by differences in physiology and morphology among species that independently influence their local occurrences. Here we use an alternate approach that examines distributional differences within a single species that is widespread in both deserts. We find that diploid and tetraploid *Larrea tridentata* occur sympatrically at an abrupt boundary in the low elevation areas of the Gila and San Pedro Rivers of southeastern Arizona. This cytotype boundary is correlated with climatic and vegetational transition, is consistent with a boundary between the Chihuahuan and Sonoran Deserts first suggested by Shreve, and raises interesting questions about the historical persistence of this contact zone.

Introduction

The Chihuahuan and Sonoran Desert biomes of North America harbor species-rich, highly endemic floras that reflect a long isolation maintained along most of their boundary by the high elevations of the Sierra Madre Occidental. At present, species from both deserts come into contact only in the lowland areas where the Sierra Madre Occidental massif fragments into smaller mountain complexes in northern Mexico and adjoining areas of the United States (Warshall 1994). Species of plants (Henrickson and Straw 1976; Mabry and others 1977; McLaughlin 1986; Shreve 1942, 1951), mammals (Riddle 1998; Riddle and others 2000), reptiles (Morafka 1977), and bees (Danforth 1994; Rozen 1992) from each desert have been documented to reach their distributional limits in this area. These biological discontinuities coupled with abrupt changes in several climatological measures (Ackerman 1941; MacEwen and others 2005; Russell 1931; Schmidt 1979) support the presence of a transition zone between the Chihuahuan and Sonoran Deserts.

Although there is a general consensus that the boundary between the Chihuahuan and Sonoran Deserts occurs where vegetation transitions to a high elevation grassland community in southeastern Arizona, southwestern New Mexico, and northeastern Sonora, uncertainty persists over the formal location of the eastern boundary of the Sonoran Desert within this region (Gehlbach 1967; Schmidt 1979; Thornthwaite 1948; Weaver and Clements 1938). This uncertainty stems in part from the use of species assemblages, or select plant species to identify a boundary. However, different physiological and morphologi-

cal traits among species invariably result in local differences in their occurrence, which are accentuated by the complex climatological and topographic variability of the “Sky Islands” area. Thus, the location of the eastern boundary of the Sonoran Desert has depended on the choice of indicator species and/or the definition of desert employed. For example, Shreve (1942, 1951) argued that the distributional limits of Saguaro Cactus (*Carnegiea gigantea*) and Ironwood (*Olneya tesota*) were closely associated with the edge of the Sonoran Desert as it transitions to the intervening grasslands currently separating the Chihuahuan and Sonoran Deserts. In contrast, Schmidt (1979) used measures of aridity to suggest the Chihuahuan and Sonoran Deserts were connected and shared a boundary in southeastern Arizona.

An approach not previously used to investigate the Chihuahuan-Sonoran Desert boundary is to examine genetic or distributional discontinuities within a single species of plant that inhabits both deserts. Single-species analyses should generally enjoy the advantage of controlling for the variable environmental effects on distantly related indicator species (Gleason 1926, 1939). Abrupt breaks in the distribution of a species, or discontinuities in DNA molecular markers, may indicate significant geological or environmental shifts. For example, Riddle (2000) demonstrated that species from multiple taxonomic groups in the North American deserts comprised divergent mitochondrial DNA lineages. Divergence of these phylogroups was found to correlate with past inundations that bisected the peninsula for species with distributions on the Baja Peninsula. We adopted a similar approach in this study using cryptic genetic variation to identify distributional shifts in the North American creosote bush (*Larrea tridentata* (DC) Coville; Zygophyllaceae).

Larrea tridentata is a ubiquitous shrub found throughout the Chihuahuan, Sonoran, and Mojave Deserts (Barbour 1969; Benson and Darrow 1981; Hunter and others 2001; Laport and others 2012; Lewis 1980; Turner and others 1995; Yang 1967, 1970; Yang and Lowe 1968). The distribution of *L. tridentata* has been used to define the extent of these deserts (Hastings and Turner 1965; Hunziker and others 1977; Shreve 1942) and its macrofossils are used to infer past desert conditions (Betancourt and others 1990). Yang (1967, 1970)

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

documented the existence of three chromosome races of creosote bush in North America. Recent analyses using guard cell measurements (Hunter and others 2001) and flow cytometry (Laport and others 2012) demonstrated that populations of tetraploids ($2n = 4x = 52$) and hexaploids ($2n = 6x = 78$) intermingle in the northern Sonoran Desert, while diploids ($2n = 2x = 26$) are limited to the Chihuahuan Desert and only hexaploids are known from the Mojave Desert.

As part of a broader study of cytotype distributions, Laport and others (2012) identified an abrupt transition between diploids and tetraploids near the classically defined boundary of the Sonoran Desert. However, it remains unclear if the diploid and tetraploid cytotypes are restricted to the Chihuahuan and Sonoran Deserts, respectively, due to the low resolution of prior sampling. Here, we describe additional sampling across this diploid-tetraploid cytotype transition and examine evidence for the presence of a concordant ecological gradient supporting a transition from the Chihuahuan to Sonoran Desert. We measured plant community composition at sites spanning the cytotype transition and used multi-decadal climate data to determine if the cytotype transition is concordant with biotic and abiotic change. Finally, we constructed Ecological Niche Models, a widely used method for generating hypotheses of species distributions (Hijmans and others 2003; Kozak and Weins 2006; Oberhauser and Peterson 2003; Roura-Pascual and others 2004) to test if bioclimatic

data predict the boundary between *L. tridentata* cytotypes. These data were then used to discuss the potential relationship of this transitional area to the historical extent of the Chihuahuan and Sonoran Deserts.

Methods

Details of the cytotype distributions discussed here can be found in Laport and others (2012). Here, we employed 15 diploid and 13 tetraploid sites from areas surrounding the Gila and San Pedro River valleys of southeastern Arizona, USA (table 1; fig. 1). These sites, as reported in Laport and others (2012), were established in spring 2007 and 2008. The cytotype of 5-50 individuals per site was inferred using flow cytometry (Laport and others 2012). Discovery of the transition between diploid and tetraploid *Larrea tridentata* prompted the establishment of seven additional sites (T1Q1, T1Q2, T1Q3, T1Q4, T1Q5, T6Q1, T6Q2; table 1) along the Gila and San Pedro Rivers in 2008, creating two sampling transects between known diploid and tetraploid sites. Each plant (650 in total) was permanently marked with a numbered aluminum tag, and the GPS coordinates of each site were recorded (table 1).

To examine if other elements of the plant community changed in conjunction with the transition from diploid to tetraploid *Larrea tridentata*, we measured vegetation attributes at five sites along the

Table 1—*L. tridentata* collection sites and 30-year averages of NOAA climate data used in statistical analyses.

Ploidy	Number Plants Sampled	Site Name	Latitude	Longitude	Altitude (m)	January Max. (°C)	January Min. (°C)	July Max. (°C)	July Min. (°C)	Annual Precip. (cm)
2x	6	AZ07-B	31.816	-110.167	1216	15.28	2.28	34.06	19.17	35.81
2x	6	AZ07-G	33.341	-110.599	1027	15.17	0.83	37.89	22.72	40.31
2x	5	AZ07-J	32.258	-110.334	988	15.83	-2.39	35.11	17.67	33.91
2x	5	AZ07-K	32.153	-110.288	—	—	—	—	—	—
2x	5	AZ07-L	32.050	-110.327	1074	15.22	-1.22	33.94	17.83	33.55
2x	20	AZ07-M	33.162	-110.400	842	15.22	-2.22	36.00	20.17	26.16
2x	20	AZ07-N	33.174	-110.512	1027	15.22	-2.22	36.00	20.17	26.16
2x	8	AZ07-O	33.178	-110.530	—	—	—	—	—	—
2x	10	AZ07-T	32.493	-110.494	843	15.83	-2.39	35.11	17.67	33.91
2x	10	AZ07-U	32.269	-110.352	—	—	—	—	—	—
2x	10	AZ08-AI	31.905	-109.743	1330	16.78	-1.44	34.17	18.00	34.95
2x	5	AZ08-AX	31.934	-110.660	1183	14.61	0.17	32.11	16.06	53.80
2x	20	AZ08-H	32.838	-109.628	965	14.56	-2.67	35.67	18.17	27.08
2x	10	NM07-G	32.636	-109.024	1241	9.56	-10.89	28.44	7.94	44.63
2x	10	SN07-C	31.314	-109.317	1191	16.78	-1.44	34.17	18.00	34.95
2x	50	T1Q1	32.521	-110.504	—	—	—	—	—	—
2x	50	T1Q2	32.556	-110.516	—	—	—	—	—	—
2x/4x	50	T1Q3	32.596	-110.539	—	—	—	—	—	—
2x	50	T1Q5	32.540	-110.507	—	—	—	—	—	—
2x	25	T6Q2	33.189	-110.551	—	—	—	—	—	—
4x	6	AZ07-A	32.078	-111.259	789	18.78	0.72	37.22	21.06	32.03
4x	20	AZ07-F	33.020	-110.743	635	15.17	0.83	37.89	22.72	40.31
4x	8	AZ07-P	33.158	-110.805	846	15.17	0.83	37.89	22.72	40.31
4x	20	AZ07-Q	33.084	-110.715	634	15.17	0.83	37.89	22.72	40.31
4x	10	AZ07-R	32.749	-110.645	707	18.17	-0.78	37.61	18.44	36.40
4x	50	AZ07-S	32.633	-110.558	809	18.17	-0.78	37.61	18.44	36.40
4x	30	AZ08-AA	32.430	-111.360	605	19.22	1.44	38.17	22.11	31.50
4x	10	AZ08-AB	32.451	-111.480	753	18.89	5.50	38.06	24.67	30.48
4x	10	AZ08-AC	32.347	-111.459	761	19.22	1.44	38.17	22.11	31.50
4x	5	AZ08-AD	32.821	-111.204	724	13.44	1.67	33.39	19.33	63.30
4x	30	AZ08-AE	33.303	-111.372	576	16.11	6.06	36.72	24.11	51.41
4x	10	AZ08-AH	31.964	-110.926	839	14.61	0.17	32.11	16.06	53.80
4x	10	AZ08-AW	31.963	-110.728	1083	14.61	0.17	32.11	16.06	53.80
4x	50	T1Q4	32.616	-110.539	—	—	—	—	—	—
4x	25	T6Q1	33.021	-110.740	—	—	—	—	—	—

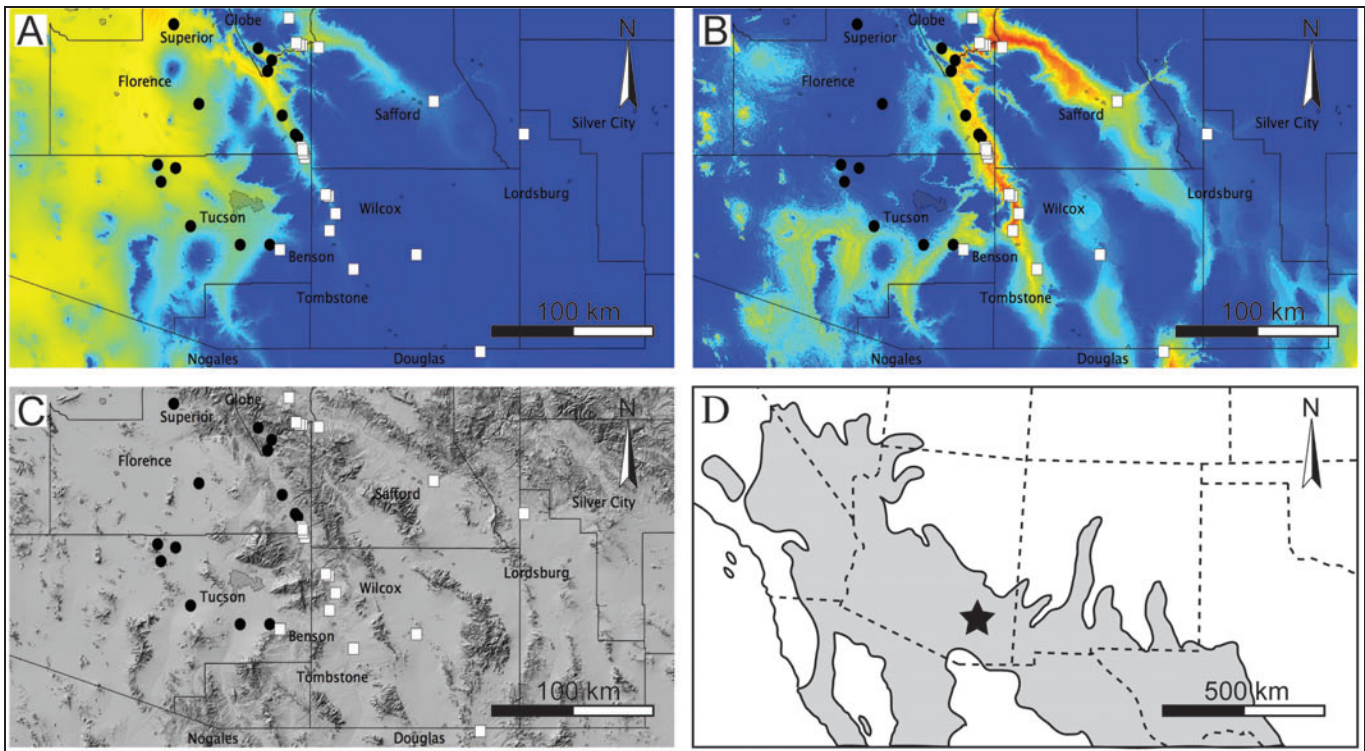


Figure 1—Ecological Niche Model projections of (A) tetraploid and (B) diploid *L. tridentata* based upon collections near the Chihuahuan/Sonoran Desert transition. Relief map (C) displaying *L. tridentata* collections in the San Pedro River and Gila River drainages of SE Arizona. Diploid sites are represented by white squares; tetraploid sites are represented by black circles. Warmer colors in the niche model projections represent higher predicted suitability. The northern range of *L. tridentata* (D) adapted from Hunziker et al. 1977. Star denotes location of study region.

San Pedro River and four sites along the Gila River (tables 1, 2). At each site, a representative 25 m x 25 m sampling plot was established in spring 2010 and the total number of each woody perennial species present was recorded (table 2). The vegan (v2.0.3) CRAN package for community ecology analyses implemented in the R statistical package (www.r-project.org) was used to conduct Nonmetric Multi-

dimensional Scaling (NMDS) ordinations on the species density data. NMDS ordinations were implemented on square-root transformed and Wisconsin double standardized data. A two-dimensional solution with stress = 0.05192 was obtained using Bray-Curtis dissimilarities and 20 random starts. This solution was selected after inspection of a dimensionality vs. stress plot revealed that stress values reached

Table 2—*L. tridentata* sites and species density data used for species ordinations. San Pedro R. sites are listed north to south, Gila R. sites are listed west to east.

River Transect	Site Name	<i>Larrea tridentata</i>	<i>Opuntia</i> spp.	<i>Cylindropuntia</i> spp.	<i>Prosopis velutina</i>	<i>Parkinsonia</i> spp.	<i>Carnegiea gigantea</i>	<i>Ferocactus wislizeni</i>	<i>Acacia greggii</i>	<i>Acacia</i> spp.	<i>Calliandra eriophylla</i>	<i>Encelia farinosa</i>	<i>Fouquieria splendens</i>	<i>Ephedra</i> spp.	<i>Simmondsia chinensis</i>	<i>Yucca</i> spp.
San Pedro	AZ-S	50	0	9	8	0	1	0	0	0	0	0	0	0	0	0
	T1Q4	77	0	19	1	2	3	1	1	0	0	0	0	0	0	0
	T1Q3	81	6	5	4	17	4	2	2	3	4	0	2	0	0	0
	T1Q5	45	13	6	9	14	11	7	6	10	0	0	0	0	0	0
	T1Q2	27	1	2	7	23	14	1	5	4	0	0	0	0	0	0
Gila	AZ-F	19	2	0	3	14	1	0	1	0	0	1	1	0	7	0
	AZ-Q	27	0	8	9	10	3	4	13	1	2	13	0	1	0	0
	T6Q2	46	0	0	1	0	5	1	1	0	12	33	5	14	23	2
	AZ-N	20	9	1	6	4	1	1	12	0	0	0	0	0	0	2

an asymptote at solutions with higher dimensionality (McCune and Grace 2002).

To test if climate differed between diploid and tetraploid sites, we obtained climate values from the closest (mean 21.4 km, range 1–45 km) National Oceanic and Atmospheric Administration (www.noaa.gov) weather stations to 12 diploid and 13 tetraploid sites (table 1). Some sites could not be paired with unique weather stations and were excluded from climate analyses. We obtained 30-year averages (longest available for all sites) for January maximum temperature, January minimum temperature, July maximum temperature, July minimum temperature, and mean annual precipitation for Analysis of Variance (ANOVA) models and Principal Components Analysis (PCA) using the JMP statistical package (v9; SAS Institute, Cary, North Carolina, USA). Altitudes were obtained from the USGS National Map (www.nationalmap.gov), as were political boundaries and bedrock geology for qualitative assessments of cytotype distributions in Quantum GIS (www.qgis.org) (fig. 1).

We modeled cytotype distributions using the occurrence data in table 1 to examine if niche models supported the observed boundary of diploid and tetraploid *Larrea tridentata*. Altitude and climate variables at 30 arcsecond resolution (“bioclim”) covering the geographic area of the *L. tridentata* localities listed in table 1 were obtained from Worldclim (www.worldclim.org; Hijmans and others 2005). To reduce inclusion of climate parameters from areas outside the distribution of *L. tridentata* and over-prediction of occurrence, the bioclim data were trimmed to encompass only the distribution of sampling localities detailed in table 1 (Pearson and others 2007; Stohlgren and others 2011). To minimize the high correlation among the 19 bioclim variables we reduced them to the six most dominant variables via Principal Component Analysis (PCA) on site-specific bioclim data (obtained using the “query” tool in Quantum GIS). The six variables retained were those most closely associated with the first six Principal Components: mean temperature of the wettest quarter, annual precipitation, mean temperature of the coldest quarter, precipitation of the driest quarter, temperature annual range, and seasonality of precipitation, respectively.

We used the program Maxent (v3.3.0b; www.cs.princeton.edu/~schapire/maxent/) with default parameter settings to construct a probabilistic niche model prediction for each cytotype (Phillips and others 2006). We ran 20 replicate models that were averaged via the crossvalidation method. Niche models for diploid and tetraploid *Larrea tridentata* were projected onto a broader region encompassing the “Sky Islands” and surrounding areas, and qualitatively reviewed in Quantum GIS (fig.1). Following Warren and others (2008) and Glor and Warren (2011), we also assessed the consistency and accuracy of the averaged predictions via the receiver operating characteristic (ROC) and the area under the ROC curve (AUC). High AUC values are generally indicative of models that predict occurrences well (Phillips and others 2006).

Results

Diploid and tetraploid sites were found in both the Gila and San Pedro River valleys. All individuals in four of the added transect sites (T1Q1, T1Q2, T1Q5, T6Q2) were diploid and all individuals in two of the sites (T1Q4, T6Q1) were tetraploid (table 1). A mixed site of 36 diploid and 14 tetraploid individuals was found near the center of the San Pedro River transect (T1Q3). Excluding this mixed-cytotype site (T1Q3), diploid and tetraploid sites were separated by ca. 7 km along the San Pedro River transect while diploid and tetraploid sites were separated by ca. 18 km along the Gila River transect.

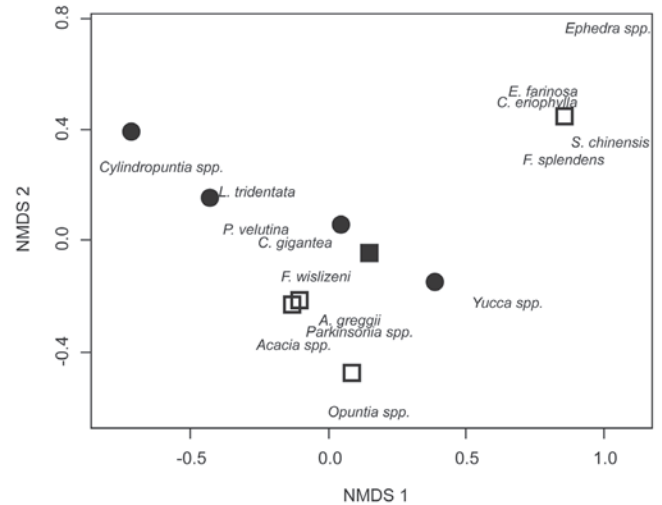


Figure 2—Non-metric Multi-Dimensional Scaling species density ordination of diploid and tetraploid sites. Diploid sites denoted by open squares, tetraploid sites denoted by black circles, the single mixed-cytotype site is denoted by a black square.

All plant species recorded in the Gila and San Pedro River transect sites had Sonoran Desert affinities (table 2) but vegetation ordination separated diploid and tetraploid sites (fig. 2). Tetraploid sites were associated with high densities of *Parkinsonia* spp., *Cyindropuntia* spp., *L. tridentata*, and *Prosopis velutina*. Diploid sites were associated with high densities of *Calliandra eriophylla*, *Carnegiea gigantea*, *Encelia farinosa*, *Ephedra* spp., *Fouquieria splendens*, *Acacia greggii*, *Opuntia* spp., *Prosopis velutina*, and *Simmondsia chinensis*. Diploid sites tended to have higher densities of Arizona Upland species than tetraploid sites.

Multiple ANOVA ($F = 3.257$, $P < 0.001$) and PCA using all climate data suggested diploid and tetraploid sites differed significantly (fig. 3).

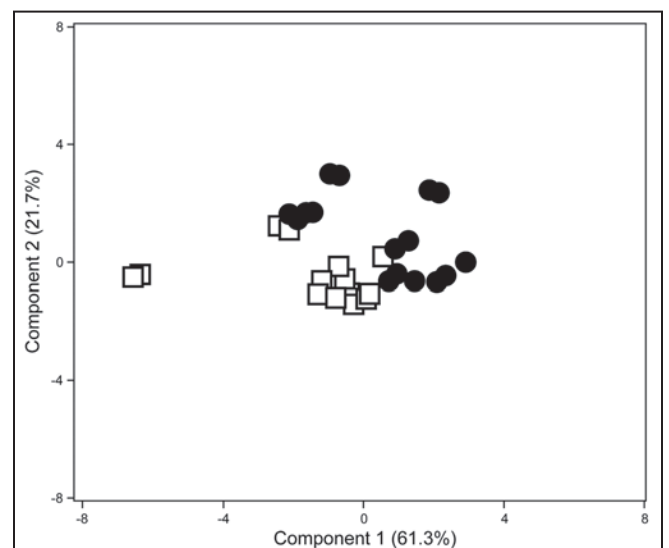


Figure 3—PCA of NOAA 30-year average climate data collected for diploid and tetraploid sites. Diploid sites denoted as open squares, tetraploid sites denoted as black circles.

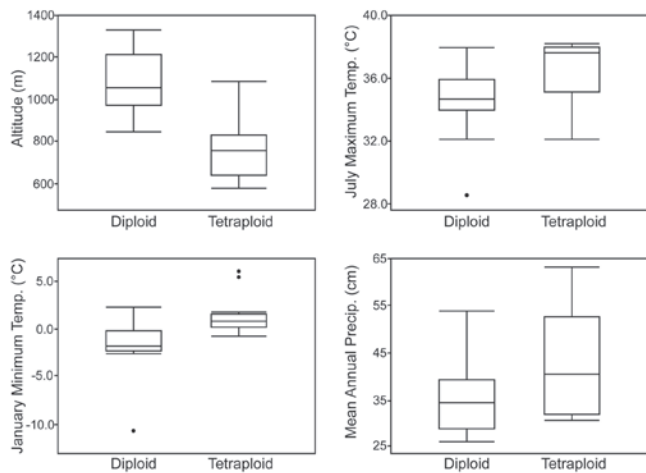


Figure 4—Boxplots of altitude and NOAA 30-year average climate data for diploid and tetraploid *L. tridentata* sites.

PC1 was associated with July maximum temperature (61.3% of variation), and PC2 was associated with mean annual precipitation (21.7% of variation). The first four Principal Components—July maximum temperature, mean annual precipitation, altitude, and January maximum temperature, respectively—accounted for 98.1% of the variation. Diploid sites tended to be at higher elevations ($F = 31.6203$, $P < 0.001$) and to have lower average temperatures (January minimum temperature, $F = 9.8483$, $P = 0.005$) (fig. 4).

Qualitatively, the niche models for diploid and tetraploid *Larrea tridentata* corresponded to the reported ranges for the individual cytotypes (Barbour 1969; Felger 2000; Hunter and others 2001; Hunziker and others 1977; Laport and others 2012; Turner and others 1995; Yang 1967; 1970). High average AUCs were obtained for both diploid (0.888, 0.178 s.d.) and tetraploid (0.893, 0.067 s.d.) niche models. The mean temperature of the wettest quarter made the largest contribution as an explanatory variable in the diploid model (39.8%), and mean temperature of the coldest quarter made the next largest contribution (29.8%). In the tetraploid model, mean temperature of the coldest quarter made the largest contribution (61.2%) and mean temperature of the wettest quarter made the next largest contribution (33.6%). Although diploids were predicted to have suitable habitat in some of the higher elevations of the Sonoran Desert, tetraploid suitability was essentially restricted to the Sonoran Desert (fig. 1). Nevertheless, diploid and tetraploid *L. tridentata* were predicted to share a boundary in the low elevations of the Gila and San Pedro River drainages, the same area where this transition is actually observed (fig. 1).

Discussion

Here, we documented an abrupt transition between diploid and tetraploid *Larrea tridentata*, a characteristic desert species, over the span of approximately 7-18 kilometers in the San Pedro and Gila River valleys of southeastern Arizona (fig. 1). A single site where diploids and tetraploids co-occur was discovered in the San Pedro River valley, an observation not previously reported. Although Yang (1970) reported the discovery of diploids and tetraploids within a 5-mile radius near Mountain View, Arizona, it is not clear if they were growing sympatrically.

Differences in plant community suggest that our Gila and San Pedro River sites occurred near the eastern boundary of the Sonoran Desert (Bahre 1995; Betancourt and others 1990; McLaughlin 1986; Schmidt 1979; Shreve 1942, 1951; Turner and others 1995). Vegetation ordination results indicate diploid and tetraploid sites differ somewhat, though not strongly, in species composition. For example, tetraploid sites had higher densities of *Larrea tridentata*, while diploid sites tended to have higher densities of Arizona Upland species such as *Calliandra eriophylla*, *Encelia farinosa*, and *Simmondsia chinensis*. The mixed-cytotype site grouped with sites where tetraploids occur (fig. 2). Surprisingly, diploid sites also had higher densities of the Sonoran Desert endemic *Carnegiea gigantea*, a species typically used as an indicator of Sonoran Desert habitat (Shreve 1951; Soule and Lowe 1970). However, the study area is located only a few kilometers north and west of the documented range limit of *C. gigantea*, as the Chihuahuan endemic *Flourensia cernua* (Benson 1969; Benson and Darrow 1981; Brown 1994; Laport personal observation; Zimmerman 1969). These species have been used variously to denote the boundaries of the Sonoran and Chihuahuan Deserts, respectively (Shreve 1951; Zimmerman 1969). The higher densities of *C. gigantea* in diploid sites may be attributable to local variation in their occurrence, or the placement of sampling plots, which could be corrected with more intensive vegetation sampling. Nevertheless, these observations can be interpreted as indicating that the study area resides in an Arizona Upland plant association (*sensu* Brown 1994) near the boundary between the Sonoran Desert and a higher elevation grassland community (*sensu* Burgess 1995), and that the diploid cytotype may not be entirely restricted to the Chihuahuan Desert and its surrounding semidesert habitat.

Altitude, precipitation, and temperature data in addition to our ecological niche models constructed from bioclim variables indicate abiotic differences occur at or near the range limits of diploid and tetraploid *Larrea tridentata*. The northwestern part of the study area is at lower elevation than the southeastern part of the study area. Tetraploid *L. tridentata* predominate in the northern and western portion of the study region while diploids were found only on the southeastern portion of the study area. Although our niche models predict some overlap between the diploid and tetraploid ranges (figs. 1, 2, 3), the overall pattern obtained from the altitude/climate data and niche models suggests areas inhabited by these two cytotypes are abiotically unique with warmer temperatures prevailing in areas where tetraploids are found. The differences observed here presumably reflect more general climatic differences between the eastern Sonoran Desert and the adjacent high elevation grassland biomes, and concur remarkably well with prior investigations of climatic differences at the boundary of the Sonoran and Chihuahuan Deserts (Ackerman 1941; MacEwen and others 2005; Russell 1931; Schmidt 1979). Despite high AUCs indicative of “good” models, the diploid model under-predicts the actual range of *L. tridentata* in SE Arizona and SW New Mexico (fig. 1B). Pearson and others (2007) suggested that niche models with limited sampling might conservatively be interpreted as indicating areas of similar climatic conditions to the known localities, rather than a model of species range limits. Nevertheless, a broader scale analysis of *L. tridentata* spanning all three North American warm deserts recapitulates the niche model differences reported here, suggesting the limited sampling of this study does not overtly bias niche model construction and projection (Laport et al. unpublished).

The results of our analyses contribute to the body of literature investigating the limits of the Chihuahuan and Sonoran Deserts. The transition between diploid and tetraploid *Larrea tridentata* over a few kilometers is generally concordant with the distributional limits of some characteristic Chihuahuan and Sonoran endemic species (i.e.,

F. cernua, *C. gigantea*) as well as a subtle climatic gradient (Benson and Darrow 1981; Schmidt 1979). Given the patterns observed in this relatively small-scale analysis, it would be informative to include additional sites and their physical features in the transition area for future analyses. We doubt soils explain cytotype distributions in this study because of the predominance of unconsolidated alluvial substrates in these river valleys. However, prior studies have demonstrated significant effects of soil on the distribution of *L. tridentata* (Ignace and Huxman 2009; McAuliffe 1994). Moreover, limestone-containing soils are common throughout the Chihuahuan Desert (Brown 1994; Wentworth 1985) and many of the diploid sites in this study appear to occur upon underlying limestone-containing sedimentary series. This includes the unsampled, but probable, boundary between diploids and tetraploids (fig. 1) in the Needle's Eye Canyon along the Gila River (Richard and others 2000; www.nationalmap.gov).

If the within-taxon analysis presented here is a reasonable indicator of where the Chihuahuan and Sonoran Desert boundary occurs, the distributions of diploid and tetraploid *Larrea tridentata* (along with other plants) suggest the current boundary between these deserts occurs within the Gila and San Pedro River valleys.

The boundary between diploids and tetraploids identified in this study may imply that a previously unrecognized zone of contact has long persisted in the low elevations of the Gila and San Pedro Rivers. No paleovegetation records have been reported for low elevations in this area, though some historical records and photographs indicate limited pockets of desert vegetation occurred among grasslands in these areas within the last 200 years (Hastings and Turner 1965; Humphrey 1987). The steep alluvial slopes near the cytotype boundary in the Needle's Eye Canyon of the Gila River (Mescal Mts., Ryan 1985) are very similar to northern extralimital populations of *Larrea tridentata* that grow on the alluvial slopes of the Rio Grande valley south of Albuquerque, New Mexico (Wislizenus 1848). These climatic conditions have likely been present for thousands of years raising the possibility that *L. tridentata* has persisted for an extended period in this ancient drainage. Future efforts to obtain paleovegetation data from pack rat (*Neotoma*) middens at low elevations in the eastern Catalina, northwestern Galiuro, and southern Mescal Mountains would be particularly informative for determining ancient botanical communities of the area, which may help elucidate the importance and persistence of the Gila and San Pedro Rivers as corridors between the Chihuahuan and Sonoran Deserts.

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Chihuahuan Desert Flora of La Calera, Municipio de Agua Prieta, Sonora, Mexico

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Abstract—A total of 555 plant collections were made on 20 trips in 2002-2008 to La Calera area in the Sierra Anibácachi, Municipio de Agua Prieta, 11.3 km south of the Arizona border (31°13'59"N 109°37'53"W, elevation range from 1220 m to 1539 m) in northeastern Sonora. Chihuahuan desertscrub on limestone substrates is dominated by creosotebush (*Larrea divaricata*), Chihuahuan whitethorn (*Acacia neovernicosa*), mariola (*Parthenium incanum*), and tarbush (*Flourensia cernua*). Riparian vegetation along a rocky bedrock/gravel wash includes desert willow (*Chilopsis linearis*), netleaf hackberry (*Celtis reticulata*), desert hackberry (*C. pallida*), woolly buckthorn (*Sideroxylon lanuginosum*), soaptree yucca (*Yucca elata*), Arizona walnut (*Juglans major*), and Coahuila juniper (*Juniperus coahuilensis*). The flora is diverse with 350 taxa in 60 families and 222 genera in 25 km² (2.5 km² extensively inventoried). Only 5.1% of the taxa are non-native. The most numerous plants are in the Poaceae (57 taxa), Asteraceae (53), Fabaceae (26), Malvaceae (22), and Euphorbiaceae (21) in the genera *Euphorbia* (11), *Abutilon* and *Bouteloua* (7 each), *Eragrostis* and *Muhlenbergia* (6 each), and *Dalea*, *Ipomoea*, and *Sphaeralcea* (5 each). Twenty-six taxa are probably the first records for Sonora. Another 21 taxa are noteworthy state records (rare or significant range extensions)..

Introduction

The Chihuahuan Desert is the largest of the three creosotebush-dominated warm deserts in North America (Shreve, 1942). It primarily occurs from New Mexico and Texas southeast through Chihuahua and Coahuila to San Luis Potosí (Lowe, 1964; Rzedowski, 1978; Brown, 1982). Most (90%) is in Mexico on the Mexican Plateau bounded to the east by the Sierra Madre Oriental and to the west by the Sierra Madre Occidental. Most of this area is above 1000 m elevation and regular incursions of frigid Arctic air from the north have shaped the evolution of the flora. More than 80% of Chihuahuan desertscrub is found on limestone and the gray gravel of this substratum give the characteristic view of the landscape (Lowe, 1964; Brown, 1982). Throughout the area, there is a mosaic of Chihuahuan desertscrub on limestone bedrock and desert grassland in fine-soiled valley bottoms. In the Santa Catalina Mountains of Arizona, Shreve (1922) and Whittaker and Niering (1968) concluded that vegetation is more xeric and open and that both vegetation and species reach higher elevations on limestone. We have noticed that this effect is most prevalent in drier Chihuahuan Desert areas, but hardly noticeable in foothills thornscrub on limestone in east-central Sonora southward.

The Chihuahuan Desert reaches its westernmost extent in southeastern Arizona and northeastern Sonora. In this paper, we study the flora in Chihuahuan desertscrub on Rancho La Calera in Sierra Anibácachi, southwest of Agua Prieta, Sonora.

Study Area

Rancho La Calera, is an isolated hill northeast of Sierra Anibácachi, ca. 10 km (by air) southwest of Agua Prieta, 11.3 km (by air) south of the United States/Mexico border 31°13'59"N 109°37'53"W (fig. 1). The vegetation on limestone substrates at 1220-1539 m elevation is Chihuahuan desertscrub. The flora is representative of an area of 25 km², with only 2.5 km² sampled intensively. The Sierra Anibácachi is formed by Lower Cretaceous limestone in the Bisbee Group, a southern extension of thick and well-exposed marine sediments in the Mule Mountains (McKee and others 2005).

The climate of the area is arid, with biseasonal rainfall, hot summers, and cold winters. Weather stations are located in Agua Prieta and Naco, Sonora. The mean annual rainfall is 353.5 mm in the Municipio of Agua Prieta, with 40-47% during the summer monsoon season in July-September. The mean annual temperature is 17.3 °C, with a summer maximum of 43 °C in June 1994 and July 1989; a winter minimum of -14 °C and wind chill of -24 °C was registered in February 2011. Low winter temperatures limit biological activities. Another climatic factor is prevailing winds from the south for more than 60% of the year, with a strength of 5.40 to 8.49 meters/second recorded in the international airport in Douglas, Arizona (Reza, 2011; CONAGUA, 2010; Universidad Autónoma de Tamaulipas, 2003).

The Sierra Anibácachi is in the Río Agua Prieta drainage basin, which is a tributary of the greater Río Yaqui. It begins as White Water Draw in Arizona before crossing the border into Sonora in Agua Prieta. The watershed area in Arizona is 2,650 km². From the border south to its junction with Río Fronteras, the Río Agua Prieta basin has an area of 1,444 km². Downstream this drainage coalesces into the Río Bavispe upstream of Lázaro Cárdenas (La Angostura) reservoir (CONAGUA 2010).

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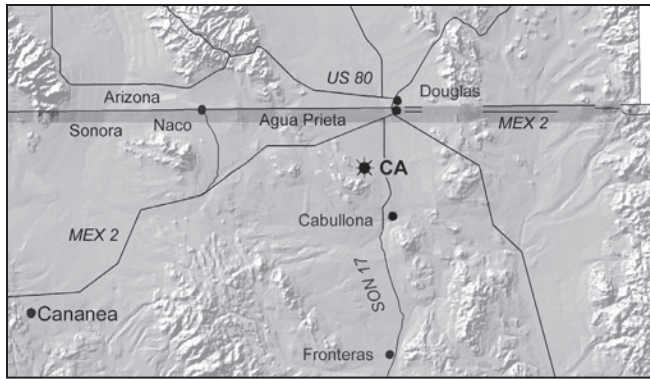


Figure 1—Map of the Rancho Calera (CA) area.

Methods

Plant Collections

Between September 2002 and May 2008, we made 20 trips to the study area, both during the summer rainy season in August–October, and the dry spring in March–June. We surveyed a broad range of habitats, including rocky slopes, peaks, cliffs, alluvial bajadas, arroyos, and cattle tanks. Most of our efforts were concentrated on the slopes and arroyo close to the La Calera ranch headquarters, and the quarry (calera) owned by Grupo México. Whenever possible we recorded plant common names from local cowboys.

We collected 590 specimens under the SEMARNAT permit to J. Jesús Sánchez-E., Curator of the Universidad de Sonora Herbarium (USON). Specimens were deposited into herbaria at the University of Arizona (ARIZ), USON, Arizona State University (ASU), and the Universidad Nacional Autónoma de México (MEXU). Although there were some previous collections from the Municipio of Agua Prieta, the Calera area had not been collected before. Specimens were identified in the University of Arizona herbarium or by specialists in other herbaria using duplicates or images. Nomenclature mostly follows the list in Van Devender and others (2010), which is available and updated in the Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org). Plant collections, observations, and photographs are available in this database. A complete list of the La Calera flora will be available as a Research Species list in the database.

Results

Vegetation

The vegetation in the La Calera study area is Chihuahuan desertscrub, which occurs on limestone bedrock, limestone-derived alluvial bajadas, and the lower fine-soiled flats. The limestone bedrock on a northeast slope is dominated by *Fouquieria splendens*, in association with the shrubs *Acacia neovernicosa*, *Calliandra eriophylla*, *Senna wislizenii*, and *Vauquelinia californica*. Additional shrubs include *A. millefolia*, *Aloysia wrightii*, *Brickellia baccharidea*, *Dalea formosa*, *Eysenhardtia orthocarpa*, *Fraxinus gooddingii*, *Mimosa biuncifera*, *Mortonia scabrella*, and *Tecoma stans*. On upper parts of ridges, *Quercus pungens* and *Bernardia myricifolia* are locally dominant. Succulents on bedrock slopes, including *Agave palmeri*, *Dasyliroton wheeleri*, *Opuntia phaeacantha*, and *Yucca baccata*, are important

in the community, as are the perennial herbs *Anemone tuberosa*, *Astrolepis cochisensis*, *Physaria fendleri*, *P. purpurea*, and *Salvia parryi*. Perennial bunch grasses, notably *Aristida purpurea* var. *nealleyi*, *Bouteloua curtispindula*, *Muhlenbergia arizonica*, and *Panicum hallii*, are common.

On the alluvial slopes, the dominants are *Acacia neovernicosa*, *Larrea divaricata*, and *Parthenium incanum*, with *Krameria erecta* and *Tiquilia canescens*. These plants are also common in flatter areas along with *Flourensia cernua* and *Prosopis velutina*. On benches above the arroyo, we found *Anisacanthus thurberi*, *Condalia warnockii*, *Forestiera angustifolia*, *F. phyllireoides*, *Koeberlinia spinosa*, and *Ziziphus obtusifolia*. Along a gravelly/rocky wash incised through the alluvium to the limestone bedrock, *Baccharis salicifolia*, *Gutierrezia microcephala*, and *Hymenoclea monogyra*, are common in riparian vegetation. In the wash, *B. sarothroides*, *Celtis reticulata*, *C. pallida*, *Chilopsis linearis*, *Sideroxylon lanuginosum*, and *Yucca elata* are occasional, and *Juglans major* and *Juniperus coahuilensis* are rare.

Flora Composition

We documented 350 taxa in 60 families and 222 genera in Chihuahuan desertscrub at La Calera. The families with more species are Poaceae (57 taxa, 16.3%), Asteraceae (53 taxa, 15.1%), Fabaceae (26 taxa, 7.4%), Malvaceae (22 taxa, 6.3%), Euphorbiaceae (21 taxa, 6.0%), Solanaceae (15 taxa, 4.3%), and Cactaceae (12 taxa, 3.4%). The genera with the most species are *Euphorbia* (11 taxa), *Abutilon* and *Bouteloua* (7 taxa each), *Eragrostis* and *Muhlenbergia* (6 taxa each), *Dalea*, *Ipomoea*, and *Sphaeralcea* (5 taxa each), *Acacia*, *Boerhavia*, *Brickellia*, *Lepidium*, *Opuntia*, and *Sporobolus* (4 taxa each). Only 18 species are non-native (5.1%), including *Cynodon dactylon*, *Eragrostis lehmanniana*, *Pennisetum ciliare*, *Sorghum halepense*, and *Tamarix chinensis*. Although those species sometimes are invasive in other areas, they do not represent an ecological threat at La Calera. The life forms of La Calera are herbs (70.0%, including grasses), woody plants (24.9%), and succulents (5.1%). The dicot herbs (188 taxa) are perennial (97 taxa) and annual (91 taxa). The grasses and sedges (57 taxa) are perennial (38 taxa) and annual (19 taxa).

Noteworthy Records—About 26 species in the La Calera area are probably the first records for Sonora, with no previous records in the MABA/SEINet database. These include *Abutilon coahuilae*, *Acurtia nana*, *Amaranthus blitoides*, *Asclepias macrotis*, *Bothriochloa laguroides* var. *laguroides*, *Chamaesaracha sordida*, *Cryptantha albida*, *Cylindropuntia leptocaulis* X *O. spinosior*, *Cyphomeris gypsophiloides*, *Dyssodia papposa*, *Fumaria parviflora*, *Gaillardia pulchella*, *Heliotropium greggii*, *H. pringlei*, *Hybanthus verticillatus*, *Ibervillea tenuisecta*, *Nolina texana*, *Opuntia macrocentra* (most other Sonoran records are misidentified *O. gosseliniana*), *Physaria fendleri*, *Physalis lagascae*, *Quercus pungens*, *Ruellia parryi*, *Simsia lagascaeformis*, *Sphaeralcea polychroma*, *Stipa eminens*, and *Vicia ludoviciana*. Most of these records represent southern extensions from the United States.

An additional 28 taxa are considered rare in Sonora: *Abutilon parvulum*, *A. wrightii*, *Asclepias nyctaginifolia*, *Bernardia myricifolia*, *Clerodendron coulteri*, *Conoclinium dissectum*, *Cryptantha pusilla*, *Erioneuron avenaceum*, *Euphorbia exstipulata*, *E. stictospora*, *Polygala scoparioides*, and *Vauquelinia californica* ssp. *pauciflora*. Other species are rarely collected in Sonora: *Dalea formosa*, *Flourensia cernua*, *Mortonia scabrella*, *Phyllanthus polygonoides*, and *Thamnosma texana*. The annual *Streptanthus carinatus* had canary yellow sepals in limestone cliffs and white sepals in sand in the arroyo. The yellow form was formerly *S. arizonicus* S. Watson var. *luteus* Kear-

ney & Peebles. It was synonymized into *S. carinatus* ssp. *arizonicus* by Kruckeberg and others (1982), but warrants reevaluation. Again most of these species are southern range extensions, but *Abutilon abutiloides*, *Physalis lagascea*, and *Ipomoea aristolochiifolia* (Austin, 2006) are northern extensions of tropical species not recorded in the United States.

Discussion

After 7 years of plant collections, the flora of the La Calera area is well represented. This is a limestone flora rich in plant species and the first Chihuahuan desertscrub flora studied in Sonora. The only North American desert characterized by trees is the subtropical Sonoran Desert, and not the more temperate Great Basin, Mohave and Chihuahuan Deserts. Only 1.7% of the La Calera flora are trees. Of these, *Celtis reticulata*, *Chilopsis linearis*, *Juglans major*, and *Juniperus coahuilensis* are riparian along the wash. *Prosopis glandulosa* and *P. velutina* are trees in other areas, but shrubs in La Calera. *Vauquelinia californica* is a tall shrub that is locally dominant on steep slopes. This species is endemic to central Arizona and adjacent Sonora, and does not occur in the main Chihuahuan Desert in New Mexico, Texas, Chihuahua, or Coahuila. The subspecies *pauciflora* is found on limestone in southeastern most Arizona and few places in Sonora. *Quercus pungens* is typically a shrub on limestone, but becomes a tree of 5-6 m height in western Texas.

Of the 85 species of native annuals, 62 (72.9%) are summer annuals, 20 (23.5%) spring annuals, and three active in either season. The abundance of summer annuals (72.9%) is interesting because to the west in the Sonoran Desert, and more so in the Mohave Desert, winter annuals are dominant.

The flora of the San Pedro Riparian National Conservation Area (SPRNCA) in Cochise County, Arizona, supports a flora of 625 taxa (56% greater than La Calera) in an area of 19,291 ha (8 times larger than La Calera; Makings, 2006). The flora of the Huachuca Mountains in Cochise County supports a flora of 917 taxa (61% greater than La Calera) in an area of 31,600 ha (12 times larger than La Calera; Bowers and McLaughlin, 1996). According to Bowers and McLaughlin (1996), species diversity is best correlated with elevational range and habitat diversity, since both temperature and precipitation vary with elevation. The La Calera flora is interesting because habitat diversity and elevational range are minimal but the flora is diverse. Wentworth (1982) documented the distributions of plant species on limestone bedrock and calcareous soils at 1400 to 1900 m elevations in the Mule Mountain. Of 232 species in these habitats, 147 are shared with La Calera. The 85 species not in La Calera were in the mesic limestone habitat in oak woodland zone, which is 400 m above the La Calera study area; i.e., *Bouvardia ternifolia*, *Cercocarpus montanus*, *Garrya wrightii*, *Quercus arizonica*, *Pinus discolor*, etc. It is especially interesting that La Calera had 203 taxa not recorded in the Mule Mountains, only 39 km west-northwest of La Calera.

The distributions of the plants in the La Calera flora are predominantly southwestern United States and northwestern Mexican, with biotic affinities to the Great Plains grasslands and the Chihuahuan Desert, which form a mosaic in most areas. *Fouquieria splendens*, *Larrea divaricata*, *Tecoma stans*, *Opuntia phaeacantha*, and *Yucca elata* are widespread. *Bernardia myricifolia*, *Acacia neovernicosa*, *Flourensia cernua*, *Mortonia scabrella*, *Nolina texana*, *Panicum hallii*, *Parthenium incanum*, *Quercus pungens*, *Salvia parryi*, *Senna wislizeni*, and *Tiquilia canescens* are Chihuahuan species mostly found on limestone or calcareous soils. *Opuntia chlorotica* primarily occurs in Arizona and adjacent southern California, southwestern New

Mexico, and northern Sonora, but not in the Chihuahuan Desert to the east.

Three species in La Calera are considered “in risk” or “candidate” species according to the Official Mexican Regulation NOM-059-ECOL-2002 (D.O.F. 2002), which establishes the degree of protection for species: *Amoreuxia palmatifida* and *Peniocereus greggii* var. *greggii* are listed as Pr [special protection] and *Juglans major* is listed as A [threatened]. None of the plants from La Calera is listed either in Arizona or the United States.

We conclude that the La Calera is a very interesting area with a rich, regionally unique flora in the westernmost Chihuahuan Desert. With records of about 40 species new to or rare in Sonora in the northwestern borderlands of the country, the flora is very important for Mexico. The Grupo México quarry operation has severely disturbed slopes on the La Calera ridge just northeast of the study area. Protection of a representative area of this habitat and vegetation is warranted. .

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Flora of Chihuahuan Desertscrub on Limestone in Northeastern Sonora, Mexico

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Abstract—Transects were done in desertscrub on limestone to characterize the flora of the westernmost Chihuahuan Desert. Most of the sites (15) were in the Municipios of Agua Prieta and Naco in northeastern Sonora, with single sites near Ascensión, northwestern Chihuahua and east of Douglas in southeastern Arizona. A total of 236 taxa were recorded on transects. Dicot perennial herbs (66 species) were the most numerous life forms, followed by annual herbs (36 species), subshrubs (36 species), and woody shrubs (33 species). The most diverse limestone floras were on Rancho La Morita in the Municipio of Naco (87 to 119 taxa/transect), Rancho La Calera (88 taxa), and Cerro El Caloso and Cerrito Los Janitos (84 taxa each) in the Municipio of Agua Prieta. Chihuahuan desertscrub at its western limits is a mixture of typical Chihuahuan species that reach Texas and Coahuila with western and tropical species in associations that are regionally distinct from other parts of the Chihuahuan Desert.

Introduction

The Chihuahuan Desert is the largest of the three creosotebush-dominated warm deserts in North America (Shreve, 1942). It primarily occurs from San Luis Potosí northwest through Chihuahua and Coahuila to Texas and New Mexico (Lowe, 1964; Rzedowski, 1978; Brown, 1982). Most (90%) is in Mexico on the Mexican Plateau bounded to the east by the Sierra Madre Oriental and to the west by the Sierra Madre Occidental. Most of this area is above 1000 m elevation and regular incursions of frigid Arctic air from the north have shaped the evolution of the flora. More than 80% of Chihuahuan desertscrub is found on limestone, and the gray gravel of this substratum give the characteristic view of the landscape (Lowe, 1964; Brown, 1982). Throughout the area, there is a mosaic of Chihuahuan desertscrub on limestone bedrock and desert grassland in fine-soiled valley bottoms. In the Santa Catalina Mountains of Arizona, Shreve (1922) and Whittaker and Niering (1968) concluded that vegetation is more xeric and open and that both vegetation and species reach higher elevations on limestone than on other substrates. We have noticed that this effect is most prevalent in northern areas with drier climates, but hardly noticeable in foothills thornscrub on limestone in east-central Sonora and tropical deciduous forest in southern Sonora.

During the spring of 2007, we attempted to relocate the endangered Cochise pincushion cactus (*Coryphantha robbinsorum*) reported from Sonora by Lopresti (1984). Although *C. robbinsorum* was not found, local floras on calcareous substrates were surveyed in northeastern Sonora and adjacent Arizona and Chihuahua (Van Devender and Reina-G., 2007). Here we use the results of these inventories to characterize Chihuahuan desertscrub at its westernmost extension.

Methods

We visited a *C. robbinsorum* population on Permian limestone on the Magoffin Ranch in Cochise County, Arizona, to refine our search image for the plant and its habitat. Potential areas for *C. robbinsorum* were identified in Sonora based on the presence of Paleozoic or lower Cretaceous limestone substrates on Instituto Nacional de Estadística y Geografía (INEGI) geological maps, the proximity to the Arizona *C. robbinsorum* populations, and habitat descriptions in Lopresti (1984). Seven areas in Sonora in the Municipios de Agua Prieta and Naco and one in Chihuahua were selected for plant inventories (table 1, fig. 1).

The climate of the area is arid, with biseasonal rainfall, hot summers, and cold winters. The weather stations nearest all transects are located in Agua Prieta and Naco, Sonora. The mean annual rainfall is 353.5 mm in the Municipio of Agua Prieta, with 40–47% during the summer monsoon season in July–September. The mean annual temperature is 17.3 °C, with a summer maximum of 43 °C in June 1994 and July 1989; a winter minimum of –14 °C and wind chill of –24 °C was registered in February 2011. Low winter temperatures limit biological activities. Another climatic factor is the prevailing wind from the south for more than 60% of the year, with a strength of 5.4 to 8.5 meters/second recorded in the international airport in Douglas, Arizona (Reza et al., 2011; CONAGUA, 2010; Universidad Autónoma de Tamaulipas, 2003).

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Table 1—Localities for limestone transects in Arizona, Chihuahua, and Sonora.

Identification	Location	Elevation	Description
Arizona			
MG 1:	Cochise County: limestone hills on Magoffin Ranch	31°22'13"N 109°08'18"W, 1284 m elevation to 31°22'00"N 109°24"W, 1311 m	(<i>Coryphantha robbinsorum</i> population). Open, grassy Chihuahuan desertscrub-desert grassland mix on very gentle slope with gray limestone bedrock on upper portions of the hill.
Chihuahua: Municipio de Ascensión			
CH1	Cerro de Cal (La Biznaga on geology map), west of Ascensión; two areas combined	31°07'04"N 108°05'23"W, 1380 m elevation and 31°06'35"N 108°05'04"W, 1322 m elevation	Open Chihuahuan desertscrub on dark gray limestone with white and orange secondary veins.
Sonora: Municipio de Agua Prieta			
AL1	Ridge above El Álamo, ca. 21 km south of the Cerro La Minita transect on Rancho Puerta Blanca, north of the Sierra Pitáicachi, ca. 2 km west of Cerro Agua Zarca, 7 km northwest of Rancho El Capadero, 9.7 km (by air) southeast of La Cieneguilla (= Oquita Montenegro) in Cajón Bonito	1239 to 1289 m elevation	Chihuahuan desertscrub on west-facing, gray, fossiliferous limestone; good grass, not heavily grazed.
AP1	ca. 15 km east of Agua Prieta on north side of MEX 2; 31°19'03"N 109°22'36"W	1318 m elevation	Chihuahuan desertscrub on gentle hill, south and northeast slopes, highly modified Cretaceous limestone with bands of whitish quartz; southern slope very grassy, northeast slope dominated by <i>Flourensia cernua</i> and <i>Acacia neoverrucosa</i> .
CA1	Rancho La Calera, ca. 10 km (by air) southwest of Agua Prieta, outlier ridge of Sierra Anibácachi	31°14'07"N 109°37'40"W, 1289 m elevation	Chihuahuan desertscrub on whitish gray limestone upper northeast-facing slope, alluvium below.
CA2	Rancho La Calera, ca. 10 km (by air) southwest of Agua Prieta, outlier ridge of Sierra Anibácachi	31°13'59"N 109°37'37"W, 1297 m elevation	Chihuahuan desertscrub on whitish gray limestone upper northwest-facing slope, alluvium below
CL1	Cerro Caloso (= Calichoso), ca. 8 km (by air) east of Cabullona	lower end: 31°08'23"N 109°28'15"W, 1215 m elevation, upper end: 31°08'14"N 109°27'59"W, 1272 m	Chihuahuan desertscrub on east-northeast facing limestone ridge with most layers nearly vertical, but with lots of bedrock exposed, dark gray (to purple) with lots of secondary white calcite veins.
JN1	Cerrito Los Janitos, east of the north end of the Sierra Anibácachi, ca. 1.5 km (by air) west-southwest of Agua Prieta	lower end: 31°15'57"N 109°40'15"W, 1334 m elevation, upper end: 31°15'56"N 109°40'27"W, 1429 m	Chihuahuan desertscrub on light gray limestone (similar to CA1 and CA2); mostly on east-facing slope.

Table 1—Continued

Identification	Location	Elevation	Description
PB1	Ca. 40 km east of Agua Prieta on Rancho Puerta Blanca, north of Arroyo Guadalupe and MEX 2, just south of Arizona border (below transect PB2)	upper end: 31°18'56"N 109°06'30"W, 1294 m elevation	Chihuahuan deserts scrub on south-southwest slope; lower part limy quartzite, upper gray limestone
PB2	Ca. 40 km east of Agua Prieta on Rancho Puerta Blanca, north of Arroyo Guadalupe and MEX 2, just south of Arizona border (above transect PB1)	upper end: 31°19'22"N 109°06'37"W, 1386 m elevation	Chihuahuan deserts scrub on south-southwest slope; gray limestone.
PB3	Ca. 37 km east of Agua Prieta on Rancho Puerta Blanca, south of MEX 2, east of Arroyo Guadalupe	31°17'58"N 109°08'40"W, 1277 m elevation	Chihuahuan deserts scrub on top of gentle north-south limestone conglomerate ridge
PB4	Ca. 37 km east of Agua Prieta on Rancho Puerta Blanca, south of MEX 2, east of Arroyo Guadalupe	31°18'04"N 109°07'36"W, 1355 m elevation	Chihuahuan deserts scrub on gentle west-facing slope, mostly loose limestone weathering from limestone conglomerate ridge.
Sonora: Municipio de Naco			
MO1	Hill west of Arroyo La Bellota, Rancho La Morita, ca. 25 km west of Agua Prieta	lower end: 31°08'23"N 109°28'15"W, 1215 m elevation, upper end: 31°08'14"N 109°27'59"W, 1272 m	Excellent gray bedrock limestone on gentle slopes (all directions) and large flat area on top; grasses common.
MO2	Hill west of Arroyo La Bellota, Rancho La Morita, ca. 25 km west of Agua Prieta	lower end: 31°15'14"N 109°49'05"W, 1438 m elevation; upper east end: 31°15'21"N 109°48'50"W, 1486 m; upper north end: 31°15'27"N 109°48'55"W, 1486 m	Chihuahuan deserts scrub. Transect began on west-facing slope with scattered gray bedrock limestone on alluvium; then to north slope bedrock on more gentle northeast slopes and hill tops.
MO3	Cerro La Bruja (north), Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta	lower end: 31°14'39"N 109°48'25"W, 1496 m elevation; upper end: 31°14'42"N 109°48'22"W, 1543 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on steep south-facing slope.
MO4	Cerro La Bruja (north), Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta (just west of MO3 transect)	lower end: 31°14'40"N 109°48'57"W, 1477 m elevation; upper end: 31°14'46"N 109°48'47"W, 1547 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on steep south-facing, open grassy slope.
MO5	Cerro La Bruja, Rancho La Morita, ca. 23 km west, 5.5 km south (by air) of Agua Prieta (across Arroyo La Bruja, southeast of MO3 and MO4 transects)	lower northwest end: 31°14'17"N 109°47'38"W, 1509 m elevation; east end: 31°14'17"N 109°47'34"W, 1520 m	Chihuahuan deserts scrub on excellent gray bedrock limestone on gentle slopes on north-facing slope and east-west ridgetop; grasses common.

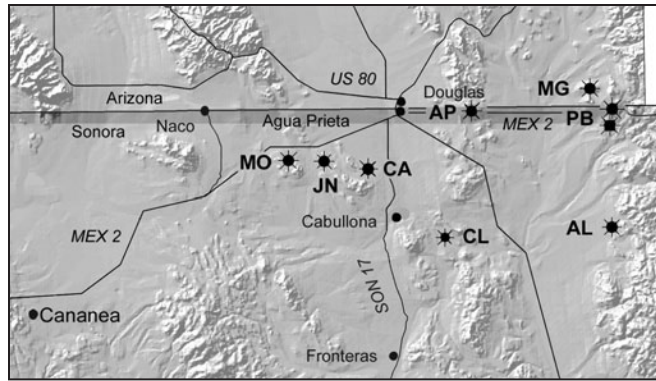


Figure 1—Map of study areas: AL = El Álamo, AP = Agua Prieta, CA = Rancho la Calera, CL = Cerro Caloso, JN = Cerrito Los Janitos, MG = Magoffin Ranch, PB = Rancho Puerta Blanca.

All of the study area except the site in Chihuahua is in the Río Agua Prieta drainage basin, a tributary of the greater Río Yaqui that begins as White Water Draw in Arizona before crossing the border into Sonora in Agua Prieta. The watershed area in Arizona is 2,650 km². From the border south to its junction with Río Fronteras, the Río Agua Prieta basin has an area of 1,444 km². Downstream these tributaries coalesce into the Río Bavispe upstream of the Lázaro Cárdenas (La Angostura) reservoir (CONAGUA 2010). The Río Yaqui itself forms when the Ríos Bavispe and Áros join north of Sahuaripa.

Plant Collections and Relevés

During the spring of 2007, plants were recorded in the seven study areas on March 23-27, April 3-19, and May 2-5 (fig. 1). A total of 17 transects were done on limestone bedrock and limestone derived alluvial surfaces. We surveyed a broad range of habitats, including rocky slopes, peaks, cliffs, alluvial bajadas, arroyos, and cattle tanks. We collected 216 specimens, which were deposited in herbaria in Mexico and the United States, including the University of Arizona (ARIZ), Universidad de Sonora (USON), Arizona State University (ASU), Universidad Autónoma Nacional de México (UNAM), and others. Collections were sponsored under a Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) permit to J. Jesús Sánchez-Escalante (USON). Semi-quantitative relevés were done to characterize the vegetation and assess species abundance. Relevés were about 0.5 hectares (50 x 100 m = 5,000 m²) in area (Mueller-Dombois and Ellenberg, 1974). All perennial plants were recorded and assigned relative abundances of rare (1-2 individuals), uncommon, common, or abundant (the most numerous); annual species were registered as present, whether alive or dead. This is a rapid assessment method readily comparable among different transects. Plant collections, observations from the relevés, and photographs are available online in the Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) database (Madrean.org). Specimens were identified in the University of Arizona herbarium or duplicates were provided to specialists. Nomenclature mostly follows Van Devender et al. (2010) and updates in SEINet. Only taxa identified to the species level were used to compare among transect floras. Plant collections, observations, and photographs are available in the SEINet/MABA database. A complete list of the transect floras will be available as a Research Species list in the database.

Results

Vegetation

The vegetation on all transects was Chihuahuan desertscrub with varying importance of desert grassland plants. Two simple measures of importance were used: (1) the number of transects a species occurred on, and (2) a relative abundance of abundant on at least one transect. A total of 47 species occurred on 10 or more of the 17 transects, and 15 species were abundant on at least one transect (table 2). The data indicate that the shrubs *Acacia neovernicosa*, *Calliandra eriophylla*, *Fouquieria splendens*, *Larrea divaricata*, *Menodora scabra*, *Parthenium incanum*, *Rhus microphylla*, and *Senna wislizenii*; the succulents *Agave palmeri*, *Cylindropuntia spinosior*, *Dasyliirion wheeleri*, *Echinocereus fendleri*, and *Opuntia phaeacantha*; and perennial grasses (seven species) are characteristic plants on limestone. Additional typical limestone plants include the shrubs *Dalea formosa* and *Flourensia cernua*, the perennial herbs *Astrolepis cochisensis*, *Bahia absinthifolia*, *Chamaesaracha sordida*, *Dalea wrightii*, *Physaria fendleri*, *Polygala macradenia*, and *Tiquilia canescens*, the perennial grass *Panicum hallii*; and the annuals *Hedeoma nanum*, *Linum puberulum*, and *Thymophylla pentachaeta*.

Table 2—Plants on ten or more transects on bedrock limestone in Arizona, Chihuahua, and Sonora. Species abundant on at least one transect in bold. NT = number of transects.

Species	NT	Species	NT
SHRUBS			
<i>Fouquieria splendens</i>	17	<i>Yucca baccata</i>	12
<i>Acacia neovernicosa</i>	16	<i>Opuntia engelmannii</i>	11
<i>Rhus microphylla</i>	15	N = 9	
<i>Aloysia wrightii</i>	13	PERENNIAL HERBS	
<i>Larrea divaricata</i>	12	<i>Astrolepis cochisensis</i>	16
<i>Condalia warnockii</i>	11	<i>Croton pottsii</i>	15
<i>Senna wislizenii</i>	11	<i>Chamaesaracha sordida</i>	13
<i>Eysenhardtia orthocarpa</i>	10	<i>Bahia absinthifolia</i>	12
<i>Flourensia cernua</i>	10	<i>Physaria fendleri</i>	12
N = 9		<i>Tiquilia canescens</i>	11
SUBSHRUBS		<i>Dalea wrightii</i>	10
<i>Calliandra eriophylla</i>	16	<i>Polygala macradenia</i>	10
<i>Menodora scabra</i>	16	N = 8	
<i>Parthenium incanum</i>	16	PERENNIAL GRASSES	
<i>Zinnia acerosa</i>	15	<i>Bouteloua curtipendula</i>	16
		<i>Aristida purpurea</i> var.	
<i>Dalea formosa</i>	14	<i>nealleyi</i>	13
<i>Hibiscus coulteri</i>	14	<i>Heteropogon contortus</i>	13
<i>Hibiscus denudatus</i>	13	<i>Bouteloua eriopoda</i>	12
<i>Gutierrezia microcephala</i>	11	<i>Dasyochloa pulchella</i>	11
N = 8		<i>Panicum hallii</i>	11
WOODY VINE		<i>Aristida ternipes</i> var. <i>ternipes</i>	10
<i>Cottisia gracilis</i>	14	N = 7	
N = 1		ANNUALS	
SUCCULENTS		<i>Hedeoma nanum</i>	16
<i>Cylindropuntia spinosior</i>	15	<i>Thymophylla pentachaeta</i>	14
<i>Dasyliirion wheeleri</i>	15	<i>Ditaxis neomexicana</i>	13
<i>Echinocereus fendleri</i>	15	<i>Linum puberulum</i>	12
<i>Opuntia phaeacantha</i>	15	<i>Galium proliferum</i>	10
<i>Agave palmeri</i>	14	N = 5	
<i>Mammillaria grahamii</i>	14	Total: 47 taxa	
<i>Cylindropuntia leptocaulis</i>	12		

Other typical limestone plants found on fewer than 10 transects or not scored abundant were the shrubs *Fraxinus gooddingii*, *Mortonia scabrella*, *Quercus pungens*, and *Rhus virens* subsp. *choriophylla*; the subshrubs *Cyphomeris gypsophiloides*, *Mentzelia oligosperma*, *Ruellia parryi*, *Salvia parryi*, and *Thymophylla acerosa*; the perennial herbs *Dalea pogonathera*, *Euphorbia villifera*, *Phyllanthus polygonoides*, *Polygala scoparioides*, *Senna bauhinoides*, *S. lindheimeriana*, *Thamnosma texana*, and *Verbesina longipes*; and the annuals *Dalea nana* var. *carnescens* and *Iva ambrosiifolia*. *Vauquelinia californica* var. *pauciflora* is a prominent shrub in the Magoffin Hills that is rare in Sonora. It was only found in the Rancho La Calera area, where it was a local dominant.

Flora Composition

We documented 236 taxa in 170 genera and 54 families in Chihuahuan desertscrub on the 17 transects. The families with most species were Asteraceae (36 taxa, 15.2%), Poaceae (33 taxa, 13.9%), Cactaceae (21 taxa, 8.8%), Fabaceae (18 taxa, 7.6%), Malvaceae and Pteridaceae (8 taxa each, 3.3%), and Euphorbiaceae (7 taxa, 2.9%). The genera with the most species were *Opuntia* (6 taxa), *Dalea*, *Bouteloua*, *Echinocereus*, and *Polygala* (5 taxa each), *Cylindropuntia*, *Abutilon*, *Aristida*, and *Muhlenbergia* (4 taxa each), and *Brickellia*, *Eragrostis*, *Physaria*, and *Senna* (3 taxa each). The life forms on transects were herbs (57.2%, including grasses), woody plants (31.3%), and succulents (11.4%). Of the dicot herbs (102 taxa), 66 taxa are perennial and 36 taxa annual, while 27 of 33 grass taxa were perennial and six annual taxa. The sampling yielded 51 to 119 taxa/transect (average 73.4 taxa/transect).

Non-Native Species—Floras on limestone in the study area only had six (2.5%) non-native species: *Eragrostis lehmanniana*, *Eragrostis cilianensis*, *Erodium cicutarium*, *Fumaria parviflora*, *Salsola tragus*, and *Sisymbrium irio*. None of them are invasive in these areas. *Eragrostis lehmanniana* is an African bunchgrass that is a serious invasive that displaces native species in desert grassland in southeastern Arizona but less so in adjacent Sonora.

Several invasive species not encountered on the limestone transects are expanding into nearby areas. The African buffelgrass (*Pennisetum ciliare*) has been widely planted in the Sonoran Desert in Arizona and Sonora. This subshrubby grass is an aggressive competitor for water and nutrients and introduces fire as an ecological process into non-fire adapted desertscrub, thornscrub, and tropical deciduous forest. It is a serious invasive species in areas mostly below 1060 m elevation. Van Devender and Dimmitt (2006) reported the expansion of buffelgrass to elevations of 1195 to 1395 m as far east as 44 km east of Agua Prieta in northeastern Sonora. In August 2007, it was found at 1565 m in desert grassland 46.5 km east of Agua Prieta. In September 2006, it was found at 1287 m elevation within a kilometer of the La Calera limestone transects. A modest-sized plant appeared in a small arroyo that had been surveyed a number of times previously. This location is well away from a paved road and the nearest plants observed along the Agua Prieta-Nacozari highway are ca. 5.5 km to the east. Also, two very small individuals were found in desert grassland on a new dirt pile on Rancho El Porvenir, east of Cabullona (close to the El Caloso transect), where dirt roads were recently bulldozed as part of mineral prospecting activities. Either seeds were transported to the area by vehicles, or blown from the highway about 6.5 km to the west. Although buffelgrass is a serious invasive in Chihuahuan desertscrub in the Big Bend of Texas, it mostly does not occur away from paved highways in northeastern Sonora. Increased temperatures

(global warming) could change its status in northeastern Sonora from non-threatening to invasive.

Sahara mustard (*Brassica tournefortii*) is a North African-European spring annual that is a serious invasive in low elevation (below ca. 800 m) Sonoran desertscrub in northwestern Sonora, southwestern Arizona, and southeastern California (Dimmitt and Van Devender, 2009). Its arrival and expansion in other parts of Sonora is more recent, as it disperses mostly along major highways. It was present in agricultural areas near Hermosillo in central Sonora in 1995 and west of Bacobampo in southern Sonora in 1993. Between 2003 and 2005, it spread southward along Mexican Federal Highway 15 (MEX 15) about 180 km from Magdalena de Kino and Santa Ana south to Hermosillo. By 2008, it was in Guaymas, another 128 kilometers to the south. In northern Sonora, it was found in 2005 at 1109 m elevation in Cíbata, 29 km south of Nogales on the Arizona border. By 2007, it was 25–41 km east of Agua Prieta along MEX 2 (156–172 km east of Nogales) at 1126–1295 m in cottonwood-willow riparian forest, Chihuahuan desertscrub, and desert grassland. By 2010, it was 48.5 km east of Agua Prieta at 1455 m elevation in desert grassland. MEX 2 is the major truck route between Baja California and Chihuahua, which crosses the Lower Colorado River Valley Sonoran desertscrub areas invaded by *B. tournefortii*.

Prior to Kearney and Peebles (1960), the European *Eruca vesicaria* ssp. *sativa* was known in Arizona from a few urban and vegetable garden settings in the Tucson and Phoenix areas. Since 1960, arugula has been known from the agricultural areas in the Sonoran Desert at Gila Bend. In the spring of 2005, it was the most abundant annual for 70 km along Interstate 8 westward from Gila Bend in an area of several hundred square kilometers (Mark A Dimmitt, pers. comm., 2006). The plants reached about a meter tall and carpeted undisturbed valleys and rocky slopes in open Sonoran desertscrub. Alarms were raised concerning its invasive potential in the Sonoran Desert, especially in Organ Pipe Cactus National Monument. In March 2012, it was observed just across the border in Sonoyta, Sonora. Another aspect of its ecological potential was uncovered with its discovery in 2007 along MEX 2 east and west of Agua Prieta, in Chihuahuan desertscrub at 1215 to 1321 m elevation. In 2009–2010, it was found 51.2 to 53.5 km east of Agua Prieta at 1495–1499 m elevation in desert grassland. In 2007, it was common in desert grassland at 1360 to 1533 m elevation in the Janos area in northwestern Chihuahua. These observations suggest that this mustard is potentially invasive in higher elevation habitats. A 2012 collection near Moctezuma in central Sonora in foothills thornscrub at 637 m elevation suggests that it may expand its range into more tropical areas as well.

Bromus rubens is a North African-Eurasian spring annual grass that is a serious invasive in California and Arizona. Fires fueled by dense spring growth are devastating to Mohave and Sonoran desertscrub, whose dominants are not well adapted to fire. It is not common or invasive in Sonora. Prior to this study, it was previously known from the Sierra Pinacate in northwestern Sonora (Felger 2000) and the Sierra el Humo south of Sásabe. In 2007–2008, it was found in Arroyo Guadalupe on Rancho Puerta Blanca, Municipio of Agua Prieta. In May 2010 it was found 41.3 km east of Agua Prieta along MEX 2 at 1323 m in desert grassland. This species appears to be spreading from disturbed areas along the border roads in Arizona into the Río Yaqui drainages and south into Sonora.

Biogeography

Our collections of *Cyphomeris gypsophiloides*, *Echinocereus fasciculatus* var. *fasciculatus*, *Euphorbia villifera*, *Mentzelia oligosperma*, *Polygala lindheimeri* var. *parvifolia*, *Quercus pungens*, and

Zephyranthes longifolia are probably the first records for the species for Sonora. The observation of *Ferocactus wislizenii* at Cerro de Cal may be the first record for Chihuahua. Many more species were previously known from Sonora from only a few records, including *Bernardia myricifolia*, *Castilleja lanata*, *Cheilanthes villosa*, *Linum lewisii*, *Mammillaria lasiacantha*, *Notholaena aschenborniana*, *Petrophytum caespitosum*, *Phyllanthus polygonoides*, *Physaria fendleri*, *Polygala scoparioides*, *Ruellia parryi*, *Salvia parryi*, *Senna lindheimeriana*, and *Vauquelinia californica* ssp. *pauciflora*.

A number of plants on the transects are mostly western species that reach as far east as the El Paso, Texas, area including *Agave palmeri*, *Aristida ternipes* var. *ternipes*, *Bebbia juncea*, *Gutierrezia microcephala*, *Mammillaria grahamii*, and *Yucca baccata*. *Cylindropuntia spinosior* is replaced to the east by the closely related *C. imbricata*. Other transect species clearly are not in the main Chihuahuan desert to the east, including *Echinocereus pseudopectinatus*, *Encelia farinosa*, *Hermannia pauciflora*, and *Vauquelinia californica*. *Cylindropuntia thurberi* and *Eysenhardtia orthocarpa* are tropical/madreal species reaching their northern range limits in northeastern Sonora or southeastern Arizona.

Wentworth (1982) documented the distributions of plant species on limestone bedrock and calcareous soils at 1400 to 1900 m elevations in the Mule Mountain. Of 232 species in these habitats, 127 are shared with the transect floras of this study. The 72 species not on the transects, including *Bouvardia ternifolia*, *Cercocarpus montanus*, *Garrya wrightii*, *Quercus arizonica*, and *Pinus discolor* were in this mesic limestone habitat in oak woodland zone, which is 400 m above the La Calera study area.

Discussion

The Chihuahuan Desert in Sonora is represented by isolated areas in the northeastern corner of the state, mainly in the municipios of Agua Prieta, Naco, Fronteras, Bavispe and Nacozari de García. The transition to the Sonoran Desert is in the west side of the Sierra El Tigre along Presa Angostura on the Río Bavispe. Brown and Lowe (1980) mapped the vegetation as an eastern patch of the Arizona Upland subdivision of the Sonoran Desert, but in actuality, it is a distinct area, perhaps the El Tigre subdivision. Farther west in Arizona (Vekol and Waterman Mountains) and northwestern Sonora (Sierra del Viejo) at lower elevations, limestone substrates support Sonoran desertscrub rather than Chihuahuan desertscrub.

The vegetation and geology on most of the areas surveyed in this study were basically similar i.e., exposed limestone bedrock and Chihuahuan desertscrub with mixed desert grassland elements with the shrubs *Acacia neovernicosa*, *Calliandra eriophylla*, *Fouquieria splendens*, *Parthenium incanum*, and perennial grasses. The abundance of grasses on the bedrock limestone habitats varied, and generally increased with elevation. The areas with the most grasses were the Magoffin Hills and Rancho La Morita habitats at 1400 to 1500 m elevation. The abundance of grasses also reflected grazing pressure. Grasses were lush on portions of Rancho Puerta Blanca on the Cuenca los Ojos Foundation reserve south of MEX 2 where livestock were removed in about 2002, but were sparse on adjacent grazed areas on Ejido Guadalupe.

While recognizing the basic similarities among all limestone habitats surveyed, there were local differences in each area surveyed. The desertscrub on the Cerro de Cal in Chihuahua was the most xerophytic, likely because the Sierra San Luis blocks winter rains and it was heavily grazed. Yet *Eriogonum wrightii* was only seen on the Magoffin Hills and Cerro de Cal transects. *Vauquelinia californica* ssp. *pauciflora* was seen on the Magoffin Hills and Rancho La Calera,

where the vegetation was much more open, with less grass and more limestone species, and much steeper slopes. On Cerrito Los Janitos, the vegetation and substrate were very similar to the nearby Rancho La Calera but without *V. californica*, and with *Mimosa biuncifera*.

Quercus pungens is a shrubby oak found on limestone substrates from Texas to southeastern Arizona. Although not previously known from Sonora, it was found on eight areas in this study, all on steep limestone slopes and ridge tops. *Koeberlinia spinosa* was only seen on two adjacent transects on Rancho Puerta Blanca north of Arroyo El Guadalupe. *Bernardia myricifolia* was only found on the two Rancho La Calera transects. *Dodonaea viscosa* was common on the El Álamo transect, but not found elsewhere. *Bebbia juncea*, *Crossosoma bigelovii*, *Cylindropuntia thurberi*, *Encelia farinosa*, *Hermannia pauciflora*, and *Lantana macropoda* were only found on Cerro El Caloso east of Cabullona. *Dalea nana*, *Elytraria imbricata*, *Euphorbia villifera*, *Petrophytum caespitosum*, *Polygala lindheimeri*, and *Senna lindheimeriana* were only found on the Rancho La Morita transects.

In summary, the species composition of Chihuahuan desertscrub at its western limits is a mixture of typical Chihuahuan species that reach Texas and Coahuila with western and tropical species in associations that are regionally distinct from other parts of the Chihuahuan Desert. This should be considered when evaluating these areas for conservation needs.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Preliminary Flora of the Sierra Bacadéhuachi, Sonora, Mexico

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Abstract—The Sierra Bacadéhuachi in east-central Sonora is the westernmost mountain range in the Sierra Madre Occidental (SMO), located east of Bacadéhuachi, Municipio de Bacadéhuachi, 34 km east of the Chihuahua border, and 165 km south of the Arizona border. The vegetation ranges from lowland foothills thornscrub up through desert grassland to oak woodland and pine-oak forest. The flora was sampled in December 1995, July 2008, June, August, and September 2011, and March 2012. The flora totals 442 taxa in 297 genera and 96 families. The most species-rich families and genera are Asteraceae (53 taxa), Fabaceae (48 taxa), Poaceae (46 taxa), *Quercus* (11 species), *Cheilanthes* (8 species), *Muhlenbergia* (7 species), *Bouteloua* (6 species), and *Pinus* (5 species). Twenty-two species are non-native (5.0%), 10 of them grasses. No species are endemic. Although tree composition and structure of the upland woodlands and forests are similar to the Yécora, Sonora, area to the south, the preliminary Bacadéhuachi flora is less diverse.

Introduction

Rzedowski (1978) pointed out that in Mexico in general, the greatest plant species diversity was in pine-oak forest at high elevation. Conservation International in 2007 named the Madrean Pine-oak Woodlands as a global biodiversity hotspot. This area included the Sierra Madre Oriental in eastern Mexico, the Sierra Madre Occidental (SMO) in western Mexico, and the Sky Island ranges north of them

into Arizona, New Mexico, and Texas. The Sierra Madre Occidental extends in western Mexico from Zacatecas and Jalisco north to Chihuahua and Sonora, Mexico (Rzedowski 1978). Highest elevations for this cordillera exceed 2800 m, and its continuity provides an important route for fauna and flora dispersing between tropical and temperate pine forests, and between tropical forests and northern grasslands. The continental divide follows the Sierra Madre northward to the upper Río Gavilán-Sierra Huachinera on the Chihuahua-Sonora border, and then through the isolated Sierra Púlpito and Sierra San Luis in Sonora and the Animas Mountains in New Mexico.

Van Devender and others (2010) summarized the flora of Sonora. The current flora documented with voucher specimens is 3672 taxa. Extensive inventories in the SMO in east-central Sonora documented 1774 taxa (48.6% of the state flora) in the Municipio de Yécora (3300 km²; Van Devender and others 2005; Van Devender and Reina-Guerrero, unpublished). We estimate that the number of plant species in the northern SMO and Sky Island ranges in Sonora to be at least 2600 species (70.8% of the state flora). In this paper we present a

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preliminary flora of the Sierra Bacadéhuachi in the westernmost SMO to further document the biodiversity in this regional hotspot.

Methods

Study Area

The Sierra Bacadéhuachi is the westernmost mountain range in the Sierra Madre Occidental, located east of Bacadéhuachi, Municipio de Bacadéhuachi, 34 km east of the Chihuahua border, and 165 km south of the Arizona border. Field activities were centered on Rincón de Guadalupe (29°50'40"N 108°58'37"W, 1680 m elevation) owned by the Catholic Archdiocese of Hermosillo. The southern portion of the Sierra Bacadéhuachi is in the Ríos Nácori Chico and Riíto drainages, with the Río Bacadéhuachi on the north, and looping around to west, all part of the greater Río Yaqui watershed. Elevations range from 700 m at Bacadéhuachi to 2400 m on the highest peak, an elevational range of about 1700 meters. Plants were observed and collected in Bacadéhuachi and the nearby arroyo, along the old and new roads between Bacadéhuachi and Nácori Chico, and the main Sierra Bacadéhuachi along the road to Rincón de Guadalupe and the high peaks above.

Plant Collections

Plants were collected under the SEMARNAT permit to J. Jesús Sánchez-Escalante, Curator of the Universidad de Sonora Herbarium (USON). Specimens were deposited into herbaria at the University of Arizona (ARIZ), USON, Arizona State University (ASU), and the Universidad Nacional Autónoma de México (MEXU). A few early plant records from the Bacadéhuachi area were found in the Southwest Environmental Information Network (SEINet) online database. In July 1940, Stephen S. White (1948), as part of his flora of the Río Bavispe region, made collections in La Palmita and the Aguage de Bacatejaca between Granados and Bacadéhuachi, and at La Galera (5 km N of Bacadéhuachi, 29°51'12"N 109°07'57"W, 715 m elevation). Between Bacadéhuachi and Nácori Chico, Joe T. Marshall collected *Quercus tuberculata* in June 1953 and Joe T. Marshall and Richard F. Felger collected *Q. emoryi* in June 1960. These were part of Marshall's general tree inventories for his 1957 book "*Birds of the Pine-oak Woodland in southern Arizona and Adjacent Mexico.*"

Otherwise, the Sierra Bacadéhuachi plant collections and observations reported here were by the authors. Ferguson along with Mark Kaib, H. Mata-Mangueros, and A. Valencia-Cordoba visited the area in December 1995. Van Devender, Reina-Guerrero, and Loyola-Reina did plant transects in 11 thornscrub (FTS) areas along the route of the new road (completed in 2011) between Bacadéhuachi and Nácori Chico, all on the southern slopes of the Sierra de Bacadéhuachi. All authors participated in a Madrean Archipelago Biodiversity Assessment (MABA) Expedition trip to the Sierra Bacadéhuachi in August 2011. Van Devender and Reina-Guerrero, with the help of David G. Bygott, Marisa Rice, and Robert Villa, observed plants in the same area in June and September 2011 and March-April 2012. Nomenclature mostly follows the list in Van Devender and others (2010), which is available and updated in the Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org). Plant collections, observations, and photographs from the study area are available in this database. A complete list of the Sierra Bacadéhuachi flora will be available as a Research Species list in the database.

Results

Vegetation

The vegetation on the southern lower flanks of the Sierra Bacadéhuachi is foothills thornscrub (FTS). This is the northern part of a very large expanse of FTS southward to where the Ríos Áros and Bavispe join to become the Río Yaqui, and merges into tropical deciduous forest (TDF) near San Nicolás.

In the Sierra Bacadéhuachi, oak woodland is above desert grassland or FTS. *Quercus chihuahuensis* is the most common oak, with rare *Q. emoryi* and *Q. tuberculata*. With increasing elevation *Q. arizonica*, *Q. oblongifolia*, *Quercus viminea*, *Pinus chihuahuana*, and *Arbutus arizonica* become more common. At higher elevations, there is a mosaic of oak woodland on drier slopes and pine-oak forest in more mesic areas. With the addition of *Q. hypoleucoides*, *Q. jonesii* (= *Q. coccolobifolia*), *Q. mcvaughii*, and *Q. tarahumara*, the oak diversity in higher woodlands is comparable to the Yécora area in the SMO (166 km south), with *Q. durifolia* notably absent. Pine-oak forest is dominated by *Pinus engelmannii*, with *P. arizonica* and *P. yecorensis* locally common, and mixed oaks, *Arbutus xalapensis*, and *Juniperus deppeana* var. *patoniana*. At the highest elevations, *P. strobiformis* is present, and *Q. rugosa* is rare, with no presence of a mixed conifer zone (no *Abies* or *Pseudotsuga*).

Riparian vegetation in drainages is linear, transecting other upland vegetation types. In the lowland tropical zone, riparian habitats are not well developed because FTS extends into the bottom of the drainages in most areas. *Populus monticola* and *Salix bonplandiana* were seen at Rancho el Carricito (916 m). The absence of *Guazuma ulmifolia* is of interest. This riparian tree is common and widespread in tropical southern Sonora, but apparently reaches its northern limit north of Tepache (53 km west-southwest) and on Rancho el Bábaco north of Sahuaripa (45 km south). White (1948) collected *P. fremontii* at La Galera (715 m) along Río Bacadéhuachi at FTS elevation. The arroyo at Rancho Agua Nueva (10 km east of Bacadéhuachi) in the desert grassland-FTS transition has *P. fremontii* and *Platanus wrightii* (1145 m). *Salix gooddingii* was only seen in Arroyo la Matancita (1600 m) in oak woodland near Rincón de Guadalupe. Riparian trees in Arroyo Campo los Padres at Rincón de Guadalupe are *Alnus oblongifolia*, *Cupressus arizonica*, and *P. wrightii*. We follow the classification used in Martin and others (1998) for vegetation names.

Flora

We identified 442 plant taxa in 298 genera and 96 families in the Sierra Bacadéhuachi area. The families with the most species are Asteraceae (53 taxa, 12.0%), Fabaceae (48 taxa, 10.9%), Poaceae (46 taxa, 10.4%), Euphorbiaceae (18 taxa, 4.1%), Pteridaceae (15 taxa, 3.4%), and Cactaceae (14 taxa, 3.2%). The genera with the most species are *Quercus* (11 taxa), *Cheilanthes* (8 taxa), *Muhlenbergia* (7 taxa), *Bouteloua* (6 taxa), *Asclepias*, *Acacia*, *Euphorbia*, *Mimosa*, and *Opuntia*, and *Pinus* (5 taxa each), and *Ambrosia*, *Salvia*, and *Solanum* (4 taxa each). The life forms in the Bacadéhuachi flora are herbs (49.5%, including grasses and sedges), woody plants (35.3%), and succulents (5.0%). Trees with 51 species (11.5%) are important in the flora and except for desert grassland, all of the vegetation types in the study area. The dicot herbs (219 taxa) are perennial (148 taxa) and annual (71 taxa). The grasses and sedges (46 taxa) are perennial (25 taxa) and annual (21 taxa).

Only 22 species are non-native (5.0%), including ten grasses. *Melinis repens* is an Afro-Asian bunchgrass present in desert grassland, which has the potential to dominate and displace native perennial grasses.

Brassica tournefortii, *Cynodon dactylon*, *Pennisetum ciliare*, and *Sorghum halepense* are invasive elsewhere in Sonora (Van Devender and others 2009), but not in the Bacadéhuachi area. *Pennisetum ciliare* is often planted in cleared desertscrub, thornscrub, and TDF in other areas in Sonora. Surprisingly, the only observation of it in the study area was 10.2 km east-southeast of Bacadéhuachi. Disturbance along the new highway will probably allow *B. tournefortii*, *P. ciliare*, and other non-native species to disperse into relatively intact FTS. *Marrubium vulgare* was locally common at Agua Nueva. Horehound or *marrubio* is a North African-Eurasian perennial herb that is almost always found in Sonora around stock corrals. It persists long after ranches are abandoned, but seldom spreads into natural habitats.

A single *B. tournefortii* was collected in the town of Bacadéhuachi. Sahara mustard is a North African-European spring annual that is a serious invasive in low elevation Sonoran desertscrub in northwestern Sonora, southwestern Arizona, and southwestern California (Dimmitt and Van Devender 2009). Its arrival and expansion in other parts of Sonora is more recent. It was present in agricultural areas near Hermosillo in central Sonora in 1995 and west of Bacobampo in southern Sonora in 1993. Its dispersal mostly follows major highways. Between 2003 and 2005, it spread southward about 180 km along Mexican Federal Highway 15 (MEX 15) from Magdalena de Kino and Santa Ana south to Hermosillo. By 2008, it was in Guaymas, another 128 km to the south. In northern Sonora, it was found at 1109 m elevation in Sierra Cbuta, 29 km south of Nogales on the Arizona border in 2005. By 2007, it was 25 to 41 km east of Agua Prieta along MEX 2 (156-172 km east of Nogales) at 1126-1295 m in cottonwood-willow riparian forest, Chihuahuan desertscrub, and desert grassland. By 2010, *B. tournefortii* was 48.5 km east of Agua Prieta at 1455 m elevation in desert grassland. Our 2012 collections of it in Baviácora in the Río Sonora valley, Granados in the Río Bavispe Valley, and Bacadéhuachi in the Río Yaqui drainage demonstrate that its dispersal into FTS in eastern Sonora is just beginning. These localities are 97 to 190 km to the northeast and east-northeast of the previous Hermosillo localities.

Discussion

In comparison with the intensely inventoried flora of the Municipio de Yécora, Sonora (36 trips in 1995-2008 by Van Devender and Reina-Guerrero) with 1774 plant taxa in 3300 km², the flora of the Sierra Bacadéhuachi with 442 taxa is preliminary. The study area with an elevational range of 1700 m and a maximum elevation of 2400 m comparable to those of the Yécora area (1660 m range, 2140 maximum elevation) potentially has a much richer flora. Its affinities are strongly with the main SMO and lowland New World tropics of northwestern Mexico. *Desmanthus illinoensis* was collected on a disturbed roadside in FTS at 692 m elevation near Bacadéhuachi in 2008. This prostrate perennial herb with white flowers is widespread in the eastern United States as far west as New Mexico, but has not yet been collected in Arizona. The *Lupinus* aff. *argenteus* was collected in pine-oak forest at ca. 2300 m elevation near Cerro la Placa in December 1995. The nearest known populations are on the Continental Divide in the northern SMO of Chihuahua (70 km NNW) and in the Santa Catalina Mountains in Arizona (335 km north-northwest), but the high-elevation Madrean lupines in Sonora need taxonomic revision. *Hexaletris revoluta* was collected in oak woodland at 1680 m elevation at Rincón de Guadalupe in April 2012. This rare orchid, which was described from near Galeana, Nuevo León, is known from Texas, New Mexico, and Arizona. The nearest locality is in the Peloncillo Mountains of southwestern New Mexico (260 km north). *Ribes dugesi* is a Madrean pine-oak forest shrub previously only known in Sonora on Mesa el Campanero near Yécora (166 km south). *Adolphia infesta*

collected in FTS at 1120 m at Rancho el Saucito (17 km southeast of Bacadéhuachi) in July 2008 is a rare spiny shrub in Sonora. *Tithonia fruticosa* is a large shrub/tree sunflower collected on Rancho el Embudo (10.3 km east of Bacadéhuachi) at 1215 m elevation in desert grassland in March 2012. Previously Carl V. Hartman collected it at Huehuerachi (Huepaverchi?) near Nácori Chico in December 1890 (NY) on the Lumholtz Expedition (Lumholtz, 1902) and Felger and Marshall collected it northeast of Nácori Chico in June 1960. This is the northernmost location for this tropical species.

The vegetation of the Sierra Bacadéhuachi is similar to that along the MEX 16 highway in the Yécora area, except that desert grassland is present and TDF is not. The northernmost TDF is in the Sierra San Javier at ca. 28°45'N. The FTS in the Sierra Bacadéhuachi is the transition from the New World tropics to the northern temperate zone. To the north, FTS is replaced by desert grassland as winters become colder and periodic fires become ecological processes. The northern limits of FTS in Sonora are at about 30°11'N east of Sinoquipe in the Río Sonora Valley and 30°26'N at Presa Angostura on the Río Bavispe at the southern end of the Sierra El Tigre.

Desert grassland is a vegetation type found from the Mexican Plateau in Coahuila, Chihuahua, and Durango north to southeastern New Mexico and western Texas and west to southeastern Arizona and northwestern Sonora. In Sonora, it occurs as far west as the Sásabe plains between the Sierra El Humo and the Baboquivari Mountains in Arizona. In northeastern Sonora, it forms a mosaic with Chihuahuan desertscrub as far south as Colonia Morelos and Carretas on the north and east sides of the Sierra el Tigre (White 1948). On the southwestern end of the Sierra Bacadéhuachi there is a large area of desert grassland dominated by *Prosopis velutina* at 1150 to ca. 1850 m elevation above FTS. This is one of the southernmost desert grassland areas in Sonora.

The flora of the SMO is not well known. The Yécora area was included in the broad Río Mayo flora area in Martin and others (1998), but the only detailed publication is on the grasses (Van Devender and others 2005). The only published partial flora of a Sonoran Sky Island Mountain range is for the Sierra El Tigre as part of White's (1948) flora of the Río Bavispe region. With the MABA/SEINet database, plant collections and observations from the SMO and various Sky Island ranges are becoming more available, but are not yet summarized in the literature. The Sierra Bacadéhuachi flora is an important contribution to the understanding of the biodiversity of the northern SMO and the Madrean Archipelago.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Comparison of the Tropical Floras of the Sierra la Madera and the Sierra Madre Occidental, Sonora, Mexico

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Abstract—The floras of the tropical vegetation in the Sky Island Sierra la Madera (SMA) near Moctezuma in northeastern Sonora (30°00'N 109°18'W) and the Yécora (YEC) area in the Sierra Madre Occidental (SMO) in eastern Sonora (28°25'N 109°15'W) were compared. The areas are 175 km apart. Tropical vegetation includes foothills thornscrub (FTS) in both areas and tropical deciduous forest (TDF) in the Yécora area. A total of 893 vascular plant taxa are known from these areas with 433 taxa in FTS and 793 in TDF. FTS in SMA and YEC (near Cúrea) had 220 and 298 taxa, with most of them also in TDF (69.5% and 82.9%). Only 83 taxa in TDF were shared between SMA and YEC (37.7% and 27.9% of the floras). The 49 FTS species in SMA but not YEC were not in TDF either, reflecting biotic influences from the Sonoran Desert (10), southwestern United States (8), Madrean Archipelago (6), and a few from oak woodland and tropical western Mexico. One species (*Pseudabutilon thurberi*) is endemic to central Sonora and adjacent Arizona. Affinities to the New World tropics are very strong in both areas. The structural dominants that define FTS are widespread, but composition varies greatly locally.

Introduction

The Madrean Archipelago is the area of isolated Sky Island (SI) mountain ranges between the Sierra Madre Occidental (SMO) in Sonora and Chihuahua and the Mogollon Rim in New Mexico and Arizona. It is an area with high biodiversity in a convergence zone of five biotic provinces with diverse topography, microclimates, and habitats: tropical temperate SMO, temperate Rocky Mountains, Great Plains-Chihuahuan Desert, Sonoran Desert, and the western Mexico lowlands tropics. The transition between the New World tropics and the northern temperate zone is at about 29°N–30°30'N in east-central Sonora, in northwestern Mexico.

Here we present results on preliminary floristic inventories in the tropical lowlands around the Sierra la Madera and compare them with the tropical vegetation in the Municipio de Yécora on the western base of the Sierra Madre Occidental. The results help characterize foothills thornscrub vegetation in Sonora.

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Study Areas

The two study areas are in east-central Sonora in the Río Yaqui drainage basin (fig. 1).

Sierra la Madera

The Sierra la Madera is a Sky Island mountain range located (ca. 29°51'N to 30°10'N, 109°25'W to 109°42'W) between Óputo (Villa Hidalgo) and Huásabas along the Río Bavispe to the east and between Cumpas and Moctezuma along the Río Moctezuma to the west (Yanes-Arvayo and others 2011). Portions of the range are in the Municipios of Cumpas, Granados, Huásabas, Moctezuma, and Villa Hidalgo. Elevations range from 615 m at Huásabas and 660 m at Moctezuma to over 2,300 m on the highest peak, an elevational range of about 1,685 meters. It is one of the higher ranges in Sonora. Most of the area is privately owned; the higher elevations are in Fracción V of the Área Natural Protegida Ajos Bavispe. The vegetation ranges from foothills thornscrub (FTS) in the lowlands to oak woodland and pine-oak forest at higher elevations. There is cottonwood-willow riparian forest along the Ríos Bavispe and Moctezuma. We follow the classification used in Martin and others (1998) for vegetation names.

Yécora Area

The Municipio de Yécora is an area of 3,300 km² on the Pacific slope of the Sierra Madre Occidental eastern Sonora. Elevation in

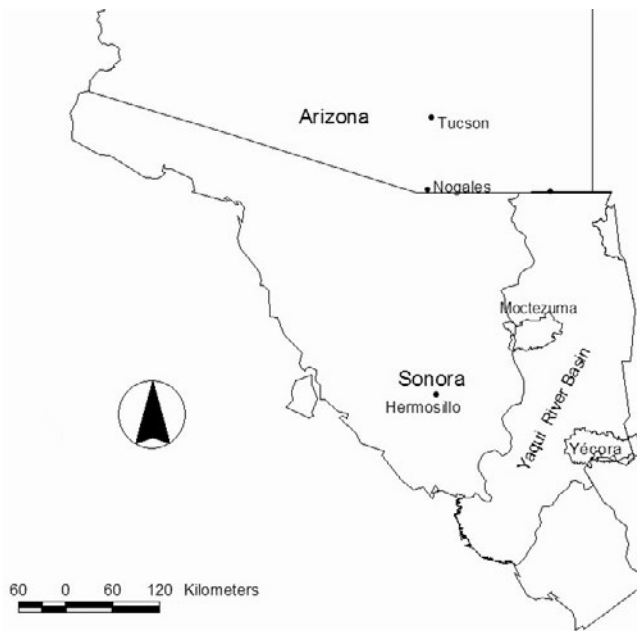


Figure 1—Study areas.

the Municipio ranges from 480 m near Curea to 2,140 m on Mesa del Campanero, an increase of 1,660 meters in 27 km (by air). Mexican Federal Highway 16 (MEX 16) is one of the few highways that crosses the SMO, providing a west-east elevational transect from foothills thornscrub near Curea (460-550 m) and tropical deciduous forest (TDF, 500-1,160 m) up through oak woodland (1,050-1,700 m) to pine-oak forest (1,220-2,240 m). Grassland occurs in high valleys (1,200-1,700 m) within oak woodland or pine-oak forest. Mixed-conifer forest (1,900-2,100 m) is present in Barranca El Salto on Mesa del Campanero.

Inventories

The Universidad de la Sierra (UNISIERRA) in Moctezuma has a long-term project to document the flora of Sierra la Madera (Yanes-Arvalo and others 2011). Only a few plants were collected in this area before the floristic efforts summarized here. The Lumholtz Expedition to the Sierra Madre Occidental followed the Río Bavispe from Óputo (Villa Hidalgo) to Huásabas and Granados in September-October 1890 (Lumholtz, 1902). The Swedish botanist Carl V. Hartman, on the Expedition, collected plants along the eastern base of the Sierra la Madera. Stephen S. White of the University of Michigan visited the Moctezuma area in 1938 as part of his floristic study of the Río Bavispe region in northeastern Sonora (White, 1948). Stephen S. Hale made a few noteworthy collections in a survey of the Tarahumara frog (*Rana tarahumarae*) in 1981 (Hale and May, 1983).

In August 2010, the Madrean Archipelago Biodiversity (MABA) Project led an expedition to the Sierra la Madera. A group of 38 scientists, researchers, students, volunteers, and Comisión Nacional de Áreas Naturales Protegidas (CONANP) made biological observations, plant collections, and images at ranchos la Barchata, las Bateas, la Cieneguita (and areas above), Mesa Quemada, and San Fernando. In September 2011, Van Devender and Reina-Guerrero observed the flora on the east slope of the Sierra la Madera west of Huásabas. Melissa Valenzuela-Yáñez (2012) as part of her undergraduate thesis

at UNISIERRA collected plants in the Ejido de Tonibabi area east of Moctezuma on eight trips in April-December 2011. Plant collections were deposited into the Universidad de Sonora (USON), University of Arizona (ARIZ), and other herbaria. All plant observations and collections, and many images are available online in the MABA database (madrean.org).

Results

We documented 220 taxa in 57 families in FTS in the Sierra la Madera. The families with the most species are Fabaceae (16.4%), Asteraceae (11.4%), Poaceae (5.9%), and Cactaceae and Malvaceae (4.5% each). The genera with the most species are *Acacia*, *Euphorbia*, and *Ipomoea* (6 taxa each), and *Bouteloua* (5 taxa). Only seven species are non-native (3.2%): i.e., *Cynodon dactylon*, *Marrubium vulgare*, *Melinis repens*, *Mollugo verticillata*, *Nasturtium officinale*, *Nicotiana glauca*, and *Pennisetum ciliare*. Only *P. ciliare* (buffelgrass) is invasive in FTS, although berro (*N. officinale*) can be very common in permanent streams. The life forms of the Sierra la Madera FTS flora are herbs (53.2%, including grasses and sedges), woody plants (40.9%), and succulents (5.5%). The herbs (103 taxa) are nearly equally perennial (54 taxa) and annual (49 taxa), with only 14 grass/sedge taxa. It is clear that there needs to be additional documentation of annuals and grasses. Although the larger woody plants and succulents are the structural dominants in FTS, their life forms are not as common as herbs: i.e., trees (10.5%), shrubs (15.9%), and subshrubs (8.7%).

The floristic affinities of the Sierra la Madera FTS are mostly tropical. Of the 49 species in the Sierra la Madera FTS that were not in Yécora FTS or TDF, 43 are native, terrestrial species. Most of them occur in the Sonoran Desert and/or desert grassland (30 each), or are widespread from the Sonoran Desert through desert grasslands to western Texas (16 species), with a total of 36 species (83.7%) in this group. The affinities are less strong with the SMO/SI (7 taxa). In the Yécora area, we documented 298 taxa in 61 families in the FTS flora. The families with the most species are Fabaceae (11.7%), Asteraceae and Poaceae (10.1% each), Euphorbiaceae (5.4%), and Convolvulaceae (4.7%). The genera with the most species are *Ipomoea* (10), *Euphorbia* (9), *Physalis* (6), and *Cyperus* and *Muhlenbergia* (5 each). There are 24 non-native species (8.0%). The life forms of the Yécora area thornscrub flora are herbs (68.8%), woody plants (29.5%), and succulents (2.0%). Twice as many herbs are annuals (111 taxa) as perennials (57 taxa). Annuals and grasses/sedges (37 taxa) are better represented than in the Sierra la Madera. Trees (7.4%), shrubs (11.4%), and subshrubs (7.0%) are the structural dominants.

Discussion

The flora of FTS has not previously been studied. We identified 220 plant taxa in FTS in the Sierra la Madera and 298 taxa in the Yécora (35% richer), with 433 taxa in both areas. Most FTS species also occur in TDF in the Yécora area (69.5% and 82.9% of the floras), which, with 793 taxa, is much more diverse than FTS. But as pointed out by Rzedowski (1978) for the Sierra Madre Occidental in general, oak woodland (809) and pine-oak forest (1081) at higher elevations on the Yécora gradient are more diverse than tropical lowland communities (Van Devender and Reina-Guerrero, unpublished).

Floristically, there are 83 taxa shared between the Sierra la Madera and Yécora FTS floras (37.7% and 27.9%, respectively). The differences between FTS in the Sierra la Madera and the Yécora area are mostly in herbs. The numbers of structurally dominant woody plants

in the two FTS floras are remarkably similar; i.e., trees (23, 24 taxa), shrubs (35, 34 taxa), subshrubs (19, 21 taxa), and woody vines (12, 11 taxa). Important FTS trees are *Acacia occidentalis*, *Bursera fagaroides*, *B. laxiflora*, *Fouquieria macdougalii*, *Ipomoea arborescens*, *Jatropha cordata*, *Lysiloma watsonii*, and *Parkinsonia praecox*, plus the shrubs *Erythrina flabelliformis*, *Eysenhardtia orthocarpa*, and *Mimosa distachya*. Woody vines with 20 species are much more diverse in TDF than FTS, and steadily decline to the west as aridity increases in the Sonoran Desert.

Deep History of Thornscrub

The uplift of the Sierra Madre Occidental (SMO) in the late Oligocene-middle Miocene (25-15 million years ago, mya) had dramatic impacts on the biota of northwestern Mexico (Van Devender, 2002). Tropical forests, once found from coast-to-coast across the continent, were restricted to the coastal lowlands. As the region gradually dried out in the Miocene, tropical deciduous forest isolated in northwestern Mexico was transformed first into thornscrub and then into desertscrub, as the Sonoran Desert formed about 8 million years ago (Axelrod, 1979). In the Pliocene (2.4-5 mya), there was a reversal to more tropical climates, when thornscrub presumably expanded back into desert areas.

The climatic changes during the Pleistocene with 15-20 glacial/interglacial climatic cycles had dramatic impacts on the Sonoran Desert as pinyon-juniper woodlands moved to low elevations in southwestern Arizona and southeastern California (Van Devender, 1990). Ice age climates differed from modern ones in much cooler summers, fewer winter freezes, reduced summer rains from tropical oceans, and increased winter precipitation from Pacific frontal storms. For 80-90% of the last two million years, the Sonoran Desert was greatly reduced in area, but thornscrub may have expanded as TDF dried out to the south.

Thornscrub

There are two types of thornscrub in Sonora (Martin and others 1998). Coastal thornscrub is on the flat coastal plain of the Gulf of California from Empalme-Guaymas southward (Friedman 1996). Foothills thornscrub is on inland rocky slopes. In southern Sonora, FTS is below TDF in elevation. In central Sonora, it is the transitional vegetation between the Plains of Sonora subdivision Sonoran desertscrub on the west and oak woodland in Sky Island mountain ranges and the Sierra Madre Occidental to the east. In the north, FTS is replaced by desert grassland as winters become colder and periodic fires become ecological processes. The northern limits of FTS in Sonora are at about 30°11'N east of Sinoquipe in the Río Sonora Valley and 30°26'N at Presa Angostura on the Río Bavispe at the southern end of the Sierra El Tigre. FTS does not reach Arizona, but the distributions of quite a few FTS species cross the border into southern Arizona in desert grassland or oak woodland.

We conclude that foothills thornscrub is a distinct vegetation type that evolved in northwestern Mexico and is best represented in Sonora,

where it is widespread, important, and under-appreciated. Our findings suggest that the floristic composition of FTS varies in different areas, but similarities in community structure (height, strata, and density) and dominants, habitats, and climate make it readily recognizable.

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Biogeographic Perspective of Speciation Among Desert Tortoises in the Genus *Gopherus*: A Preliminary Evaluation

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Abstract—The enduring processes of time, climate, and adaptation have sculpted the distribution of organisms we observe in the Sonoran Desert. One such organism is Morafka's desert tortoise, *Gopherus morafkai*. We apply a genomic approach to identify the evolutionary processes driving diversity in this species and present preliminary findings and emerging hypotheses. The Sonoran Desert form of the tortoise exhibits a continuum of genetic similarity spanning 850 km of Sonoran desertscrub extending from Empalme, Sonora, to Kingman, Arizona. However, at the ecotone between desertscrub and foothills thornscrub we identify a distinct, Sinaloan lineage and this occurrence suggests a more complex evolutionary history for *G. morafkai*. By using multiple loci from throughout the tortoise's genome, we aim to determine if divergence between these lineages occurred in allopatry, and further to investigate for signatures of past or current genetic introgression. This international, collaborative project will assist state and federal agencies in developing management strategies that best preserve the evolutionary potential of Morafka's desert tortoise. Ultimately, an understanding of the evolutionary history of desert tortoises will not only clarify the forces that have driven the divergence in this group, but also contribute to our knowledge of the biogeographic history of the Southwestern deserts and how diversity is maintained within them.

Introduction

The diverse assemblages of flora and fauna in the Sonoran Desert have been sculpted by the enduring processes of time, climate, and adaptation. The Sonoran Desert developed gradually over the last 8 million years through multiple glacial and interglacial climatic cycles that resulted in repeatedly expanding and shrinking woodlands, desertscrub, and thornscrub communities (Van Devender 1990). The modern characteristic assemblage that includes columnar cactus and

palo verde trees that define Arizona Upland Sonoran desertscrub likely did not (re)emerge until roughly 9,000 years ago (Van Devender 1990). We are interested in how this fluctuating vegetation community has shaped the evolution of one of the Sonoran Desert's most charismatic reptiles, the Morafka's desert tortoise, *Gopherus morafkai*. In particular, we explore how genetic variation within this species fits the biogeographic history of the landscape.

The genus *Gopherus* contains two species of desert tortoise, one native to the Mojave and Colorado deserts (Agassiz's desert tortoise; *G. agassizii*) and another in the Sonoran Desert region (Morafka's desert tortoise, *G. morafkai*; Murphy and others 2011). *Gopherus agassizii* occurs almost entirely north and west of the Colorado River and *G. morafkai* inhabits regions south and east of the Colorado River, extending southward into tropical deciduous forests of Southern Sonora, Northern Sinaloa, and extreme Southwestern Chihuahua. The Mojave and Sonoran lineages of *Gopherus* differ in morphology, seasonal activity, reproductive ecology, habitat selection, and genetics

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(e.g., Lamb and others 1989; McLuckie and others. 1999; Berry and others 2002).

The U.S. Fish and Wildlife Service federally listed the Mojave population of the desert tortoise (*G. agassizii*) as threatened (USFWS 1990). The Sonoran population (*G. morafkai*) is not federally listed in the United States, but became a candidate for federal listing in 2010 and is considered a Species of Special Concern in Arizona (USFWS 2010). Mexican populations of *Gopherus* receive protection as threatened species (Category A “Amenazada” in NOM-059; D.O.F. 2002). To assess trends in Morafka’s desert tortoise, it is necessary to consider populations in Mexico that occupy about two-thirds of the geographic range. Unfortunately, little data exist on the distribution, ecology, and taxonomic status of the tortoise in Mexico. Driven by this lack of knowledge, in 2005 a team of Mexican, Canadian, and American collaborators began a multifaceted study of desert tortoises throughout their range in Mexico focusing on the tortoises’ health, genetics, general biology, and ecology to investigate their status and assess conservation needs. Here we present preliminary findings and our emerging hypotheses.

Across its large geographic range in Mexico, Morafka’s desert tortoise occupies a variety of habitats including desertscrub, foothills thornscrub, and the northern part of semiarid Sinaloan tropical deciduous forest (TDF) of southern Sonora and northern Sinaloa (Fritts and Jennings 1994). Behavioral patterns and ecological challenges for tortoises in these different environments can vary greatly, but there is currently very little published on the behavior or ecology of tortoises in thornscrub and TDF communities. Genetically, mitochondrial DNA (mtDNA) sampled from tortoises in the southern portion of the range is deeply divergent from haplotypes in the central part of the species’ range, suggesting the potential for a unique lineage (Lamb and others 1989; Berry and others 2002). Thus, one challenge currently facing conservation initiatives for *G. morafkai* is to determine the taxonomic status and distribution in the southern portion of its range. The “Sinaloan” type tortoise may be a cryptic species (Murphy and others 2011).

Taxonomic assessments of tortoises in Mexico can be bolstered by identifying geographic barriers to dispersal that contribute to genetic isolation, analogous to the Colorado River, which separates *G. agassizii* and *G. morafkai*. In contrast, the identification of genetic clines infers that taxonomic recognition of multiple species is unwarranted because such designations would serve to recognize the extremes only. It is equally critical to understand the rates and patterns of genetic differentiation expected between two populations. Previous work has established that in both Mojave and Sonoran environments, desert tortoises exhibit a population genetic structure of isolation by distance (IBD; Edwards and others 2004; Murphy and others 2007; Hagerty and others 2011). IBD occurs when the geographic distance between populations is the major limitation to gene flow. Panmixia is expected at all sampling localities yet allele frequencies at sites separated by great geographic distances may differ significantly. In contrast, when alleles that distinguish species boundaries are under strong selection, the rate of genetic introgression should be near zero in one or both directions (Payseur 2010).

Methods

Between 2005 and 2011 we collected blood samples from over 130 wild-caught *G. morafkai* throughout the species’ range in Mexico and in three different vegetation communities: TDF, foothills thornscrub, and Sonoran desertscrub. Targeted sampling involved the ecotone

between foothills thornscrub and Sonoran desertscrub (fig. 1). We collected whole blood via subcarapacial or brachial venipuncture. We also used salvaged red blood cells stored at the University of Arizona Genetics Core. Blood collection followed Animal Use Protocols approved by the Royal Ontario Museum Animal Care Committee, and by the University of Arizona (IACUC 09-138). All genetic procedures and analyses were conducted in the University of Arizona Genetics Core following procedures described in Edwards and others (2004) and Murphy and others (2007). We genotyped individuals for 16 microsatellite loci (Edwards and others 2004; Murphy and others. 2007) and sequenced approximately 1,200 base pair portions of mtDNA (Murphy and others 2007). In addition, we utilized additional samples from throughout the range of desert tortoises in the United States (Edwards and others 2004; Murphy and others 2007; Edwards and others 2010).

We used PAUP* 4.0b10 (Swofford 2002) to reconstruct the maternal (mtDNA) phylogeny using a 50% majority rule consensus tree based on unweighted maximum parsimony analysis. In addition to the samples collected in this study, we also included data from *G. morafkai* collected in Arizona, *G. agassizii* collected in California and Utah (Murphy *et al.* 2007), and we utilized other *Gopherus* spp. (*G. berlandieri*, *G. flavomarginatus* and *G. polyphemus*) as outgroups.

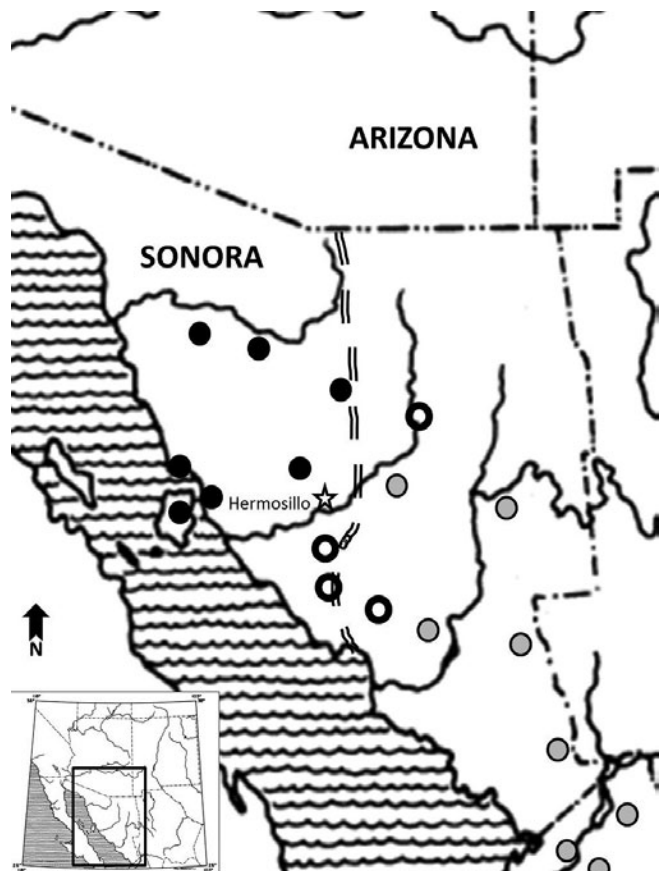


Figure 1—Sample locations in Mexico for this study are represented by circles; solid circles represent sites where the sampled mitochondrial haplogroup is strictly “Sonoran,” gray-shaded circles represent sites where the sampled mitochondrial haplogroup is strictly “Sinaloan” and open circles represent sites where a mix of Sonoran and Sinaloan haplotypes are observed. The double-dashed vertical line running down the middle of the image roughly defines the boundary of Sonoran desertscrub.

We performed a bootstrap analysis with 1,000 replicates of 10 random addition sequences per replicate to determine the support for the inferred relationships. For our microsatellite analyses we incorporated samples previously collected in Arizona and estimated the degree of population differentiation within and among populations using AMOVA (analysis of molecular variance) in ARLEQUIN 3.5.1.2 (Excoffier and others 2005). We calculated genetic distances based on pairwise Φ_{ST} (F_{ST} sensu Weir and Cockerham 1984) and defined populations by their proximity to major cities; Kingman, Phoenix, and Tucson, Arizona, USA, and Hermosillo, Ciudad Obregón, and Álamos, Sonora, Mexico.

Results

Analyses of mtDNA sequences resolved three distinct maternal lineages corresponding to the Mojave, Sonoran, and Sinaloan populations. Sonoran and Sinaloan tortoises differentiated along the ecotone between foothills thornscrub and Sonoran desertscrub. Distinct Sinaloan haplotypes occurred only in foothills thornscrub and TDF environments while Sonoran haplotypes were mostly restricted to desertscrub environments (fig. 1). Several sample sites along the ecotone of foothills thornscrub and desertscrub exhibited individuals representing both Sonoran and Sinaloan maternal lineages (fig. 1). Modal Sonoran haplotype SON01 (Murphy *et al.* 2007) was observed at all sites exhibiting Sonoran lineages.

In the analyses of bi-parentally inherited microsatellite loci we observed a continuum of genetic similarity spanning 850 km of Sonoran desertscrub, ranging from Hermosillo, Sonora, northwards to Kingman, Arizona (table 1). This corresponded with the distribution of Sonoran mtDNA haplotype SON01. Tortoises within this continuum had a population structure consistent with IBD (Mantel test: $r^2 = 0.75$, $p < 0.01$). However, strength of the correlation began to break down when assessed across the ecotonal boundary between desertscrub and thornscrub-TDF (Mantel test: $r^2 = 0.38$, $p < 0.01$). Fixed differences in microsatellite alleles occurred in foothills thornscrub and TDF in southern Sonora and clearly distinguish a unique Sinaloan genotype.

Discussion

These analyses suggest that tortoises living in foothills thornscrub and TDF in southern Sonora and Sinaloa have a level of differentiation equal to that between *G. agassizii* and *G. morafkai* from Arizona

(Murphy and others 2011). All three lineages—Mojave, Sonoran, and Sinaloan—likely diverged from a common ancestor 5–6 million years ago (fig. 2; Lamb and others 1989; Avise and others 1992; McLuckie and others 1999). A cursory analysis of the three mtDNA lineages suggests they are on independent evolutionary trajectories and potentially constitute separate species. However, spatial overlap of several haplotypes occurs at the eastern and southern boundaries

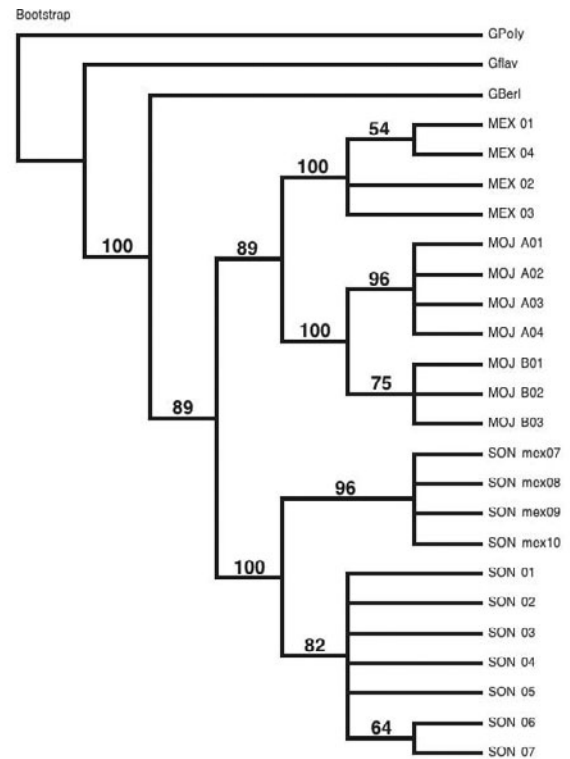


Figure 2—A 50% majority rule consensus tree based on maximum parsimony for 1,200 base pairs of sequence from the ND4 region of the mitochondrial genome of desert tortoises (*Gopherus* spp.); SON = *G. morafkai*, SON mex = mtDNA haplotypes observed only in Sonora, Mexico, MOJ = *G. agassizii*, MEX = Sinaloan populations of *Gopherus morafkai* and outgroups *G. berli* (*G. berlandieri*), *G. flav* (*G. flavomarginatus*), and *G. poly* (*G. polyphemus*). Numbers above branches are bootstrap values.

Table 1—Comparison of pairwise genetic distance, Φ_{ST} (F_{ST} sensu Weir and Cockerham 1984), among sites spanning the geographic range of desert tortoises in the Sonoran Desert. Data generated from 16 microsatellite loci. Sites are categorized by their proximity to major cities; Kingman, Phoenix, and Tucson, Arizona, USA, and Hermosillo, Ciudad Obregón, and Álamos, Sonora, Mexico. Dotted line indicates transition from localities representing desertscrub (above) and thornscrub and tropical deciduous forest (below). This analysis was performed excluding samples from the 4 sites with mixed mitochondrial lineages.

	Kingman	Phoenix	Picacho	Tucson	Hermosillo	Obregón
Kingman						
Phoenix	0.007					
Picacho	0.043	0.024				
Tucson	0.067	0.042	0.008			
Hermosillo	0.090	0.055	0.051	0.041		
Obregón	0.251	0.201	0.185	0.181	0.145	
Álamos	0.231	0.191	0.173	0.172	0.153	0.072

of Sonoran desertscrub and this suggests a complex history in this vegetative transition zone (fig. 1). The transitions from desertscrub to thornscrub to TDF are generally considered gradual, clinal transitions between somewhat artificial categories. Even though about 85% of foothills thornscrub is in Sonora, phytogeographers have characterized it as “Sinaloan” as a result of floristic affinities to TDF (Brown 1982). This ecotone is likely to have expanded and retreated many times during the relatively recent transformation into the Sonoran Desert (Van Devender 2000) and this dynamic system has undoubtedly influenced genetic differentiation among desert tortoise lineages.

Whereas the divergence between *G. agassizii* and *G. morafkai* is a classic example of allopatric speciation resulting from geographic isolation by the Colorado River (Lamb and others 1989; Avise and others 1992; McLuckie and others 1999; Murphy and others 2011), divergence of Sonoran and Sinaloan *G. morafkai* suggests that a different mechanism is in play. Sonoran and Sinaloan tortoises differentiate along an ecotone of foothills thornscrub and Sonoran desertscrub communities; ecotones can play critical roles in evolution because hybridization can occur in these settings (Barton and Hewitt 1985). Interestingly, our analyses do not detect clear signals of hybridization between Sinaloan and Sonoran type tortoises despite the spatial proximity of lineages in this extensive vegetative transition zone (fig. 1). This is in contrast to *G. agassizii* and *G. morafkai* where hybridization has been observed at locations of secondary contact (Edwards and others 2010). Unlike the clear allopatric pattern of divergence between *G. agassizii* and *G. morafkai*, Sonoran-Sinaloan lineages of *G. morafkai* may have diverged under a parapatric model where the current contact zone in Mexico may be a result of recent secondary contact after isolation prior to the formation of the Sonoran Desert. Chance interbreeding (during times of sympatry) may have driven or be driving the development of reproductive isolating mechanisms. Alternatively, the sharp break in the cline may be a result of insufficient time for genes to flow far beyond the boundary. Our future efforts will attempt to discern whether genetic differentiation is a result of past periods of isolation, or if differentiation has evolved in the absence of physical barriers to gene flow.

Taxonomic clarification is of utmost importance for management of *G. morafkai*. Our continuing effort to resolve the taxonomy of the species in the context of its geographic distribution will provide a basis for prioritizing resources and conservation measures where they are most needed and will ensure that data are available to maintain genetic diversity across the species' range. Future efforts will resolve the taxonomic uncertainty of *G. morafkai* in Mexico by testing the null hypothesis of conspecificity and determining the mechanism(s) of divergence between the Sonoran and Sinaloan lineages. Clarification of these evolutionary processes will directly inform efforts to preserve the evolutionary potential of the species. Ultimately, an understanding of the evolutionary history of desert tortoises will not only clarify the forces that have driven differentiation in this group, but also contribute to our knowledge of the biogeographic history of the Southwest deserts and how diversity is maintained within them.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Richness of Mammals on the San Bernardino Ranch in the Municipality of Agua Prieta, Sonora, Mexico

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Abstract—Historically, the San Bernardino Ranch has performed, as economical activities, livestock and farming, which has contributed to the deterioration of regional ecosystems. The ranch is ecologically important due to the diverse types of habitats of conservation interest such as the semi-desert grassland, the riparian vegetation, and a large ciénega, in which restoration efforts are being applied through water harvesting by gabions. Mammals are essential in the ecosystem. Knowing about the actual species that live on the different sites of the ranch tells us about the healthy state of the environments. We used the direct and indirect sampling methods to identify 26 species of terrestrial mammals on the Ranch. Using this information, we compared the richness and diversity of the ranch species with the species living in the San Bernardino National Wildlife Refuge located next to the border, which was a helpful comparison since the Refuge has more years of restoration experience than does the San Bernardino Ranch.

Introduction

Due to the biogeographic location, Sonora is in a transition zone between the Nearctic and Neotropical region, and is considered an arid region because its large surface is covered by desert shrubs; however, there are deciduous forests in the southern part of the state and pine-oak woodlands in the Sierra Madre Occidental, providing a diversity of ecosystems (Molina-Freaner and Van Devender 2009). This diversity is a reflection of the mammals in the state including the presence of 126 identified species and 35 as possible occurrences (Castillo and others 2010). Mammals are a fundamental part in an ecosystem covering a huge variety of niches. Some species, like carnivores, are indicators of the healthy state of the ecosystem and are key in the maintenance of an ecological balance; they also provide data for diagnosing conservation

Several areas of Sonora are considered of special interest because their resources are important to the population, as is the case of the San Bernardino Ranch, located at the Northeastern border with the United States inside the priority land region (RTP) number 45 denominated by San Luis-Janos. This area contains the headwaters of the Rio Yaqui River and is important for the diverse ecosystems of grasslands and mountains (Arriaga and others 2000) consisting of a series of tributary rivers and streams (Hudson and others 2005) with vegetation of pine-oak woodlands, low open forest, chaparral, thornless shrub, grasslands, mesquites and chollal (Rzedowski 1978).

According to the classification of provinces by Caire (1978), there are five mammal provinces in Sonora with the Mapími province covering the San Bernardino area having the highest diversity of rodents in Sonora. There was a big ciénega about 7000 years ago where the

San Bernardino Ranch is presently located. But with the arrival of the Europeans, the Cienega became a field supporting agricultural crops and livestock grazing, causing the deterioration of the habitat. This area now is part of southeast Arizona and northeast Sonora (Minckley and others 2006).

According to Castillo and others (2010), rivers in the region function like tropical fauna corridors to the north, while the foothills of Sierra Madre Occidental function as corridors as well, allowing interchange of species between the north moist temperate and south tropical regions. Such is the case of Neotropical species of great interest like jaguar (*Panthera onca*), ocelot (*Leopardus pardalis*) and jaguarundi (*Puma yagouaroundi*), which historically had their north limit in southern Arizona (Grigione and others 2007). Herein is the importance of conserving this area.

The main concerns for conservation on the San Bernardino Ranch is the Agua Prieta-Janos road, which is the international border with United States of America, with a history of residual degradation (CEDES 2011). The first efforts for conserving the general area were undertaken in 1982, when the U.S. Fish and Wildlife Service declared the area in Arizona as San Bernardino National Wildlife Refuge for the protection of water resources and to provide a habitat for native species. This area has a register of 315 bird species, 55 amphibians and reptiles, and 66 species of mammals and more than 490 types of plants according to the U.S. Fish and Wildlife Service (<http://www.fws.gov/refuges/profiles/index.cfm?id=22523>).

In Sonora, the conservation efforts in the area are carried out by the Association “Cuenca Los Ojos A C,” who work to restore the eroded soil, recharge groundwater aquifers, and promote original vegetation growth. However, these efforts are carried out only half of the time as those in the San Bernardino NWR so we do not know whether the health of the ecosystem is similar on both sides of the border. A listing of the small non-flying mammal species of the San Bernardino Ranch will help us to know more about the health of the ecosystem. Obtaining such a listing was the purpose of this study. One of the principal motives that led us to undertake this work was the demand for biological inventories of the fauna resources of the state and particularly about mammals. Also, whether similar mammal

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species occur on the San Bernardino Ranch and the San Bernardino NWR may help to determine better ways of environmental management. Therefore, determining the mammal species of this Ranch will provide interesting information about the restoration efforts that are taking place nowadays, and will help us know how these efforts are improving the state of the ecosystem in this important area for wildlife.

Methodology

The study was made on the San Bernardino Ranch, located in the northeast corner of the Sonora state in Mexico, 30 km from Agua Prieta within the coordinates of 31°19' 0.20" N y 109° 15' 59.91" W. This study was conducted as a part of our professional practices during the summer of 2011 from June 27 to July. We later came back in winter 2012 from March 15-18 to expand our database.

We used two types of methods: direct sampling and non-direct sampling. With the direct method, we captured small- and medium-sized mammals and we were able to obtain information on their weight, sex, reproductive state, body measurements, and other characteristics that helped us understand the biology of the studied species. With the non-direct method we collected information about the species without direct measurements by identifying mammals by associated tracks like pad prints, scats, body parts, and nests.

Direct Sampling Methods

To know the specific richness of small (non-flying) mammals of the San Bernardino Ranch, we established three study sites: one located near a dam (Site 1), another localized in Silver Creek (Site 2) and a third in the Cienega (Site 3). The criteria for selecting these sites were the closeness to water and being able to place the traps on a gradient from more to less humidity. The coordinates were taken at the beginning and ending of the each studied transect on each site.

The method of capture and recapture was used, which can be used for measuring the population structure (Krebs 1985). To capture small mammals, 10 Sherman traps were placed on four lines on each site and were separated by 10 m from one another, totaling a total of 40 traps for each site. Every trap was baited with a mixture of peanut butter and seeds, like oats, on 3 nights at each site. Every night the traps were baited and activated. In the morning (5 AM), the traps were checked for captures. Each collected individual was marked with purple ink and measured from total body, tail, ear, rear foot, and weight. Identification was determined through field guides. The individual was then release on the site of the capture.

For medium mammals, eight Tomahawk traps were placed around each site. These traps were baited with sardine, tuna, egg, and fresh vegetables. For each individual captured, the guides of Whitaker (1996) and Reid (2006) were consulted for their identification. All captured animals were released back into their area of capture after identification.

Non-Direct Sampling

Non-direct sampling was used to know the presence of some medium and large mammals. For this purpose we made walks on the main paths of the Ranch looking for tracks, footprints, scats, remains, and other marks. When these indicators were found, we used a scale and a camera with GPS to take pictures and obtain coordinates of each associated trace. The field guides of Aranda (2000) and Elbronch (2003) were used for identification of the traces. There were also five interviews with people of the Ranch (supported by illustrations)

between the ages of 16 and 61 years to provide an idea of the mammals that we might find.

Results and Discussion

The total registration of mammals obtained in the study was 26 species in the two sampling seasons of the year. This information was distributed in 4 orders, 11 families and 17 genera. The order with higher number of species was Rodentia with 14 (53.84% of total results) and seconded by the Carnivora order with 7 species representing 26.92%, a listing of which is presented in table 1. The 26 species register for the San Bernardino Ranch represent 20.63% of the total species of Sonora. This highlights the importance of conserving the mammals on the ranch.

Through the direct methods for small (non-flying) mammals, the total presence registered was 89 individuals, while there were 8 skunks (*Mephitis mephitis*) captured in the Tomahawk traps as summarized in table 2. The results of the non-direct methods of recoding medium-large mammals were the 43 proved observations shown in table 3, giving us a total of 140 proved data for the San Bernardino Ranch, which are included in the MABA data base.

Within the observed species, there was Desert shrew (*Notiosorex crawfordi*), the only species in the category of special protection (Pr) according to NOM-059-SEMARNAT-2010. We found in the Red List of IUCN that all registered species are under the category of least concern, but the populations of Mountain Lion (*Puma concolor*) and hog-nose skunk are under consideration for listing.

Through interviewing the people of the Ranch, we identified species such as Ringtale (*Bassariscus astutus*), Western spotted skunk (*Spilogale gracilis*), Cotton-tailed Rabbit (*Sylvilagus audubonii*), Pocket gopher (*Thomomys bottae*) and Badger (*Taxidea taxus*), but they were not included in the listing because of the lack of confirmation of their presence. We collected three skulls of dead animals that were taken to the Mammals Collection in the laboratory of terrestrial resources of the University of Sonora; further results are presented by the study sites in the following paragraphs.

Site 1

On this site we found the greatest amount of available water. This site is dominated by bulrush (*Scirpus americanus*) and was the site with more sampling success in the summer. *Sigmodon arizonae* was the species with more observations; this can be due to this species being associated with dense grasses to feed and make their burrows (Wilson and Ruff 1999). This was the only site where we found the desert shrew (*N. crawfortii*) in an area dominated by scrub. The site was relocated in the winter due to the increased amount of water. In this season we had more observations including two species, *Neotoma albigula* and *N. Mexicana*, which we did not have in the first phase of the study.

Site 2

We only had 2 individuals of *Chaetodipus penicillatus* and three skunks (*M. mephitis*) in the Tomahawk traps in the summer; this small number of captures might be because of the conditions of the site. Most of the area had bare ground, which does not provide adequate shelter for rodents. This number changed drastically in the winter, with observations of 28 individuals and 7 different species, resulting in the most captured individuals and with a major number of species at this site. This finding makes us think that the relation between the

Table 1—List of the mammals found in the San Bernardino Ranch.

Small non-flying mammals population	IUCN ^a	Medium and large mammals population	IUCN ^a
RODENTIA		LAGOMORPHA	
Familia Cricetidae		Familia Leporidae	
<i>Sigmodon arizonae</i>	Unknown	<i>Lepus californicus</i>	Stable
<i>Sigmodon hispidus</i>	Increasing	CARNIVORA	
<i>Reithrodontomys megalotis</i> ^b	Stable	Familia Canidae	
	Stable	<i>Canis latrans</i>	Increasing
<i>Reithrodontomys montanus</i> ^c	Stable	<i>Urocyon cinereoargenteus</i> ^b	Stable
<i>Peromyscus maniculatus</i>	Stable	Familia Felidae	
<i>Peromyscus leucopus</i>	Stable	<i>Lynx rufus</i> ^b	Stable
<i>Peromyscus boylii</i> ^c	Stable	<i>Puma concolor</i> ^b	Decreasing
<i>Peromyscus eremicus</i>	Stable	Familia Mephitidae	
<i>Baiomys taylori</i>	Stable	<i>Conepatus leuconotus</i> ^b	Decreasing
Familia Muridae		<i>Mephitis mephitis</i>	Stable
<i>Neotoma albigula</i> ^c	Stable	Familia Procyonidae	
<i>Neotoma mexicana</i> ^c	Stable	<i>Procyon lotor</i>	Increasing
Familia Heteromyidae		ARTIODACTYLA	
<i>Chaetodipus penicillatus</i>	Stable	Familia Tyassuidae	
<i>Chaetodipus intermedius</i>	Stable	<i>Pecari tajacu</i>	Stable
SORICOMORPHA		Familia Cervidae	
Familia Soricidae		<i>Odocoileus hemionus</i> ^b	Stable
<i>Notiosorex crawfordi</i> ^b	Stable	<i>Odocoileus virginianus</i>	Stable

^aRed list of threatened species by the International Union for Conservation of Nature.

^bSpecies found only in Summer.

^cSpecies found only in Winter.

Table 2—Total records of small non-flying mammals.

Species	Records of species	
	Summer	Winter
<i>Sigmodon arizonae</i>	10	3
<i>Sigmodon hispidus</i>	3	5
<i>Reithrodontomys megalotis</i>	1	0
<i>Reithrodontomys fulvencens</i>	3	0
<i>Reithrodontomys montanus</i>	0	1
<i>Peromyscus maniculatus</i>	5	9
<i>Peromyscus leucops</i>	1	19
<i>Peromyscus boylii</i>	0	2
<i>Peromyscus eremicus</i>	0	13
<i>Notiosorex crawfordi</i>	1	0
<i>Chaetodispus penisillatus</i>	2	2
<i>Chaetodispus intermedius</i>	2	2
<i>Bayomys taylori</i>	1	1
<i>Neotoma albigula</i>	0	2
<i>Neotoma mexicana</i>	0	1
Total records	89	

presence of water and the number of individuals was due to the dates of water flow in Silver Creek and a high density of vegetation giving a good habitat for rodents.

Site 3

On this site we expected to find the species of *S. ochrognathus* that has been recorded in the San Bernardino NWR but not found on this side of the border. However, we found the only individual of the species *Baiomys taylori*. The number of species and individuals

Table 3—Total records of medium and large mammals.

Species	Record of species	
	Summer	Winter
<i>Puma concolor</i>	7	0
<i>Procyon lotor</i>	7	1
<i>Conepatus leuconotus</i>	1	0
<i>Mephitis mephitis</i>	5	5
<i>Pecari tajacu</i>	3	2
<i>Odocoileus hemionus</i>	2	0
<i>Urocyon cinereoargenteus</i>	1	0
<i>Lepus californicus</i>	2	0
<i>Canis latrans</i>	2	2
<i>Lynx rufus</i>	11	0
Total records	51	

increased in the winter and it was the only place where we found an individual of the species *Reithrodontomys montanus*.

Associated Traces

The bobcat (*Lynx rufus*), followed by the raccoon (*Procyon lotor*), were the species with more traces that had many footprints over the paths, mainly on the shores of the rivers and also it was possible to observe some latrines on fallen trees and over gabions with water, which can indicate the adoption for these places with water (Urban 1970). We also observed raccoon scats, a variety of insects, little mammals, and some molluscs.

We did not find many skunk scats (*M. mephitis*), probably due to the aleatory selection of defecation or to hidden places like rock crevices; however, the footprints were common on the paths (Elbroch 2003). The fewest tracks we observed were of gray fox (*Urocyon cinereo-*

argenteus). This may have been due to the avoidance of competing with another carnivore like coyote that has similar preys; on occasion, coyotes can depredate the gray fox (Merlin and Siminski 2000). We found a few traces of mountain lion (*Puma concolor*), which is normal due to being a top predator and less common than the rest of the animals because of their solitary and territorial nature. However, their presence tells us about the good conditions of the place correlated to the abundance of the preys (Pacheco and others 2004).

Conclusions

The San Bernardino Ranch is a place that is undergoing restoration, and, therefore, it is possible to observe favorable changes in the fauna composition. These changes are reflected in the individual and traces found near water, which is fundamental to the establishment of species richness. Comparing our list of species and the list of the San Bernardino NWR, we can see that many species remain to be documented, due to the fact of the differences between the time of restoration on the side of the United States and Mexico. However, we recommend that this study be continued to constantly sample mammals in the San Bernardino Ranch for several years in a major amount of points to obtain reliable results.

The San Bernardino Ranch is a great site for future research efforts centered on monitoring the fauna with trap cameras, determining the population structure of small mammals, and studying the eating habits of carnivores. This type of research can show us a broader picture about the healthy state of the ecosystem in the Ranch. The purpose of the work presented in this paper was to obtain presence data. However, the necessary preliminary data were also taken for future research on the population structures of small (non-flying) mammals.

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Preliminary List of Flying Mammals in the Ajos-Bavispe National Forest Reserve and Wildlife Refuge, Sonora

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Abstract—Information on bat communities, including their composition, abundance, distribution and ecology, can support management programs in protected areas, and also provide information and initiatives for the designation of new protected areas. In 2010 and 2011, monitoring was conducted in the Ajos Mountains, a sky island, that is part of the Ajos Bavispe Reserve. During this period of time, we recorded a total of eight species (*Myotis californicus*, *Myotis auriculus*, *Myotis volans*, *Myotis thysanodes*, *Lasiurus cinereus*, *Lasiurus blossevillii*, *Eptesicus fuscus* y *Choeronycteris mexicana*), in riparian and oak-pine forests. This preliminary species list will assist in assessing ecosystem health in this part of the reserve and provides an example of the monitoring we are hoping to extend to the other Sky Islands within the Ajos-Bavispe Natural Protected Area: La Madera, El Tigre, Buenos Aires and La Purica. The intention of this paper is to use the information we have gathered on abundance and distribution of bat species as a tool to assess the conservation status and ecosystem health of these Sky Islands. Bats are a good indicator taxon because they are abundant, diverse, and relatively easy and cost effective to monitor. As a result the status of bat communities (composition and abundance) will support conservation and management decisions in the short and long term in this important protected area.

Introduction

Research on the abundance, diversity, distribution, ecology, and species composition is an essential part of the development and implementation of management programs in natural protected areas (Kalko 1993). Therefore, it is necessary to develop projects and monitoring protocols for natural protected areas to complement and guarantee the conservation of the ecosystems with proper management of resources over time.

Castner and others (1996) conducted an inventory of bats in wet Beaver Creek Wilderness Area (Coconino National Forest) to establish a bat management project which implies the importance of and results in the preservation of bats. The National Forest Reserve and Refuge Fauna Silvestre Ajos- Bavispe (RFN y RFS Ajos-Bavispe), are the oldest reserves of Mexico. They were designated in the first decree in 1936 and included barely 21,494 hectares of national land formed by

the mountains of “Los Ajos”, “Buenos Aires” and “Purica”. By 1939, the Presidential Decree was ratified adding a total of 184 000 hectares including the sierras “El Tigre” and “Pilares of Teras”, “Pilares of Nacozari”, “San Diego”, and “la Madera”. RFN y RFS Ajos-Bavispe is located in the physiographic region of the Sierra Madre Occidental (CONANP 2001). These ranges are part of the region called islands of the sky (The Sky Islands) and are known to be complex systems with uniquely high biodiversity (McLaughlin 1995; Warshall 1995).

Information on flora and fauna of Ajos Bavispe, a Protected Natural Area (ANP) has been collected in recent years; however, information on volant mammals (bats) in the ANP is not known. We believe that bats can be used as indicators to assess the conservation status of different ecosystems present within the reserve, because of their diversity, and the relative ease and cost effectiveness of monitoring bats.

The order Chiroptera is ecologically diverse and has a global distribution. The development of flight and the sophisticated sensory adaptations (echolocation) of these flying mammals has allowed bats to inhabit extremely diverse habitats and has provided them with the ability to exploit a wide variety of resources for food (Sampaio and others 2003, Ávila Flores and Medellín 2004).

This study is intended to provide an inventory of bats for the RFN y RFS Ajos-Bavispe and thus identify sites with greatest diversity and abundance. This information will be used for planning and decision

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making of refuge management when prioritizing conservation actions and habitat protection.

Methodology

Sampling was conducted in section 4 of the RFN y RFS Ajos-Bavispe situated in the Sierra Los Ajos in Gallery forests and pine-oak forest. In addition abandoned buildings, caves and mine adits were sampled. All sample sites were near perennial water sources. The sample sites are: Cañon de Evans, La Sal and El Guerigo (fig. 1).

The monitoring took place in October 2010 and May, July and August 2011, by surveying for bats with mistnets (Ávila and Medellín, 2004; Rabe and Rosenstock 2005). Three to four mistnets of 3, 6, 9 and 12 m (Martínez 2007; Sánchez and Medellín 2007) were deployed at sunset. Sampling was concluded when bat activity was no longer detectable or when weather conditions (i.e. low temperatures, high winds or rain) necessitated closing the nets. The mist nets were installed close to or over bodies of water, and in flyways used by bats (Lopez and Garcia 2006). For the monitoring in abandoned buildings, caves or mines hand nets were used to capture and identify bats (Lopez and Garcia 2006).

Captured bats were identified and sex, age (adult or juvenile), reproductive status (pregnant, nursing, post-lactante, scrotal, non-breeding, not scrotal), weight, forearm length and ear length (Ávila and Medellín 2004; Lopez and Vaughan 2004; Russell and others 2005; López and García 2006; Sánchez and Medellín 2007;) were recorded. For species identification a key to the bats of Mexico (Medellín and

others 2008) was used and when necessary we consulted experts to assist in species determination. For taking measurements we used dial calipers (DialMax) and a ruler, mass was measured with a pesola scale (100 g) and photos were taken of all captured bat species.

Results and Discussion

During our surveys in 2010-2011 we recorded a total of eight bat species (*Choeronycteris mexicana*, *Myotis auricolus*, *Myotis californicus*, *Myotis thysanodes*, *Myotis volans*, *Eptesicus fuscus*, *Lasiurus blossevilli* and *Lasiurus cinereus*) in our study sites. These species represent two families of bats Phyllostomidae (leaf-nosed bats) and Vespertilionidae (Vesper or evening bats) (table 1). Our sample recorded 34% of the 23 possible species that may occur in this area according to distribution maps in Medellín and others (2008).

Choeronycteris mexicana was found in an abandoned cabin in the months July and August and we estimated the number of individuals by having three observers count individuals at the same time. This method yielded a result of 90 to 100 estimated individuals. The discovery of this colony for the ANP is important evidence that the Ajos Mountains are being used as a roost by this important pollinating bat species which is listed as threatened in the NOM-059 (SEMARNAT 2010). We plan to monitor this roost at Güerigo regularly in order to obtain additional information on size and times of roost use. This information will assist in determining the actions necessary for protection of this colony by the ANP.

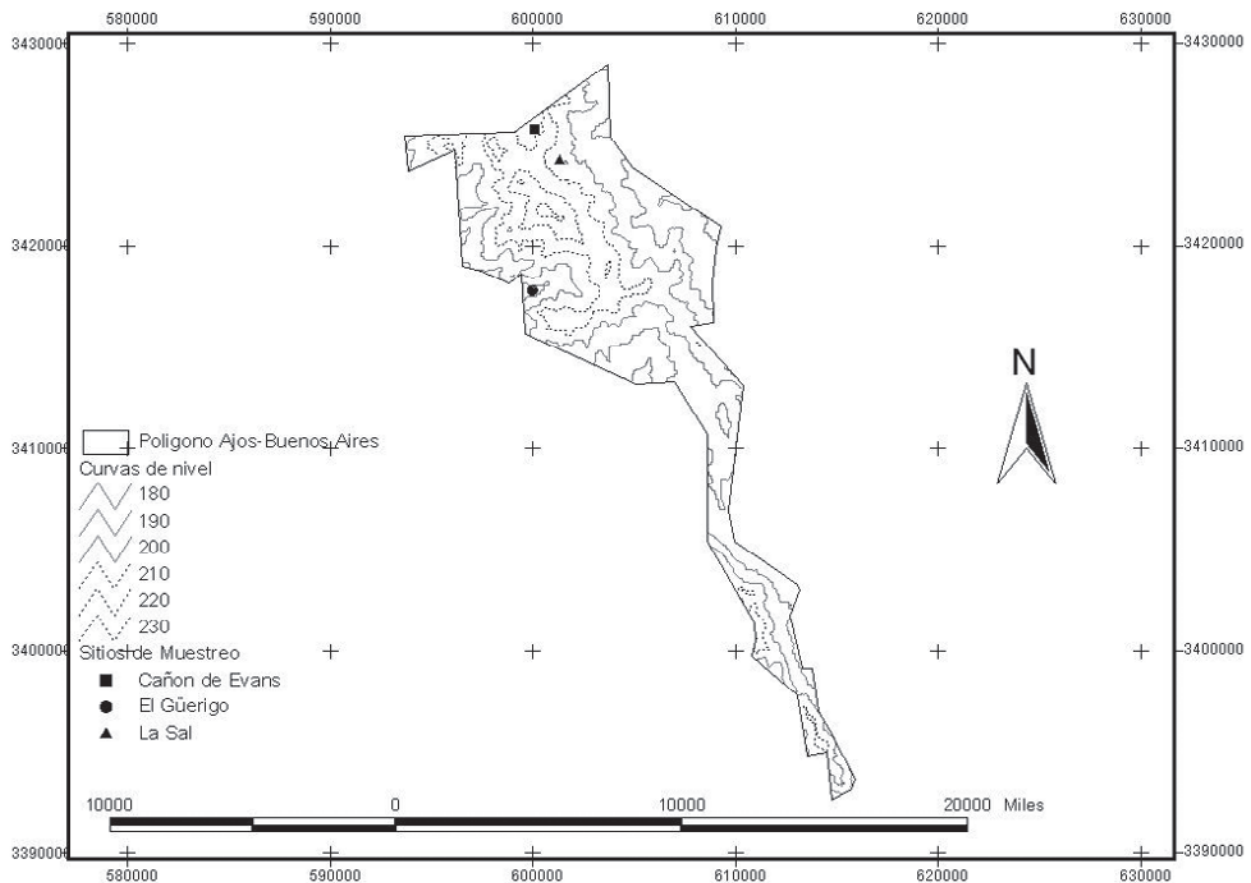


Figure 1—This map depicts the monitoring locations for bats in the Los Ajos Mountains.

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Table 1—Displays the documented species in RFN and RFS Ajos-Bavispe.

Family	Scientific name	Common name	Number of individuals
Phyllostomidae	<i>Choeronycteris mexicana</i>	Murciélago nariz de cochi	90-100
Vespertilionidae	<i>Myotis auriculus</i>	Miotis Suroeste	7
	<i>Myotis californicus</i>	Murciélago de California	5
	<i>Myotis thysanodes</i>	Miotis Bordado	6
	<i>Myotis volans</i>	Murciélago de patas largas	2
	<i>Eptesicus fuscus</i>	Murciélago grande café	7
	<i>Lasiurus blossevilli</i>	Murciélago rojo occidental	2
	<i>Lasiurus cinereus</i>	Murciélago canoso	4

This species uses a wide range of habitats including desert scrub, deciduous tropical forests and pine-oak forests (Arroyo - Cabrales and others 1987). Our study found *C. mexicana* associated with oak forest and forest galleries represented mainly by *Quercus oblongifolia*, *Quercus eggersii*, *Juniperus deppeana* and forest of galleries represented chiefly by alder (*Platanus wrightii*), alamos (*Populus fremontii*), and güerigos (*Populus brandegeei*).

Arroyo-Cabrales and others (1987) writes that for *C. mexicana* migration to Arizona and New Mexico may take place in June, however, we recorded the presence of this colony in July and August 2011; it is clear that more population and ecological data of this colony is needed to understand this species spatial and temporal use of the habitat in the Sky Island region. A better understanding of its dynamics is needed to make decisions for species conservation. *Myotis auriculus*, *Myotis californicus*, *Myotis thysanodes*, *Myotis volans*, *Eptesicus fuscus*, *Lasiurus blossevilli*, *Lasiurus cinereus*, were found in Oak-Juniper Forests and forest riparian forests represented mainly by *Quercus arizonica*, *Juniperus deppeana*, *Acer grandidentatum*, *Platanus wrightii*, with perennial water sources. Even though these species may occur in various types of habitat, the habitat they use is usually in good condition (Shump and Shump 1982, Warner Richard 1982, Warner and Czaplewsky 1984; Simpson 1993; Avila and Fenton 2005). As preliminary result we can assume that the Canyon de Evans and La Sal are in good condition and we recommended the use these sites as permanent monitoring stations to obtain abundance, diversity, and community structure data for the bat species present in the reserve.

No settlements or anthropogenic activities (i.e. livestock, agriculture) are within these sampled sites. They are nationally owned lands which have resulted in a good quality of habitat, as mentioned above these three sites have perennial water sources. For the Cañon of Evans and la Sal, we recorded the presence of *Ambystoma rosaceum* which are indicators of good water quality (Rorabaugh 2008) and complement the ecological importance of these sites in the Sierra Ajos.

A greater sampling effort is needed at the study sites, especially in the early spring. Bat surveys at additional sites within the Ajos mountains are necessary for a comprehensive assessment of the area. Also it is important to include Sierra del Tigre, Madera and the Purica which are part of the ANP in future sampling efforts.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Decade of Wildlife Tracking in the Sky Islands

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***Abstract**— In 2001 Sky Island Alliance developed a citizen science program that uses track and sign identification and count surveys to monitor potential wildlife corridors throughout southeastern Arizona and southwestern New Mexico. The goal of the Wildlife Linkages Program is to protect and advocate for an interconnected landscape where wildlife, based on their ecological needs, can move easily between core habitats, the Sky Island mountain ranges. Currently, we train and engage volunteers in the monitoring of fifty 1.5-mile long transects within seven priority linkage areas; the majority of these study areas are located on public lands. To date we have conducted over 1,000 track count surveys and documented over 4,100 records for more than 40 different animal species in the region. Sky Island Alliance has successfully applied the resulting species presence data to land-use policy and permanent land conservation, incorporating wildlife data and corridor priorities into the Sonoran Desert Conservation Plan, the Santa Cruz County Comprehensive Plan, the Pima County Wildlife Connectivity Assessment, and the Arizona Wildlife Linkages Assessment.*

Introduction

The ability for long-ranging species to disperse between mountain ranges and intervening valleys is paramount to species survival (Opdam 1990; Hass 2000; Bennet 2003; Arizona Wildlife Linkages Workgroup 2006). Preserving, restoring, and increasing connected ecosystems within the Sky Island region, has ever-greater urgency. Habitat fragmentation and destruction of open space caused by irresponsible off-road vehicle use and the development of new roads and highways, transmission lines, border infrastructure, and other effects of rapid human expansion are the most serious short-term threats to Sky Island species and their habitats (Avila and others *in press*). Division of otherwise continuous habitat will prevent natural movements of some species whose distribution in the U.S is already limited, confining them to isolation and potential extinction. In an elevational gradient, limiting wildlife migration movements from lower desert regions to higher elevations could be devastating (Miszta and others 2012). This would also have far-reaching effects on other, interconnected species, such as prey.

In the arid southwest, where extreme summer temperatures and long distances between water sources already affect species survival, climate change is adding another layer of difficulty. The ability of species to adapt and respond to a changing climate will depend on their ability to move freely across the landscape (Miszta and others 2012). An intact healthy landscape maintains the ability of wildlife to move between core areas where species—both plant and animal—have

sufficient resources to survive, reproduce, and otherwise facilitate ecological processes (Hass 2000; Soulé and Terborgh 1999).

Tracking is an excellent tool for wildlife corridor monitoring over time. The skill of wildlife tracking is hundreds of thousands of years old and seen by some as the origin of science (Long and others 2008; CyberTracker Conservation 2012). Although somewhat forgotten except as a primitive skill and recreational practice, tracking as a technique continues to have implications for modern science and for wildlife conservation (Haynes and others 2005; CyberTracker Conservation 2012).

Tracking is a non-invasive monitoring technique that, with deliberate and careful study design, can provide presence, relative abundance, occurrence, distribution, and population density information (Long and others 2008). Wildlife tracking is also an effective tool to engage and educate the public, and attracts a wide range of people from different backgrounds as supporters and advocates for wildlife and their habitats. Track count events have become extremely valuable in bringing together activists, hunters, biologists, agency representatives, military personnel, planners, landowners, academics and volunteers in a shared interest (Linton 2003; Lamberton, Avila and Morris 2011; Sky Island Alliance 2012). Track and sign identification has some limitations in terms of its subjectivity, variable observer skills, and difficulty in distinguishing individual animals, determining gender, or estimating populations.

Tracking remains a cost-effective, easy to learn, and engaging monitoring method by which we can document trends in sign detection over time and wildlife presence in specific areas, particularly with protocols to provide data consistency based on a scientific study design (Haynes and others 2005; Beier and Cunningham 1996; Smallwood and Fitzhugh 1995; Lamberton, Avila and Morris 2011). In addition, track and sign surveys can confirm the presence of rare species in new areas (Long and others 2008; Squires and others 2004). For example, Sky Island Alliance's first documentation of jaguar in the Sierra Azul range of Sonora, Mexico, came from the tracks discovered in 2009, one year before the animal triggered a nearby remote camera.

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In 2001, Sky Island Alliance (SIA) developed a citizen science program that uses track and sign identification and surveys to monitor potential wildlife corridors throughout southeastern Arizona and southwestern New Mexico. The goal of the Wildlife Linkages Program is to protect and advocate for an interconnected landscape where wildlife, based on their ecological needs, can move easily between core habitats, the Sky Island mountain ranges. We use wildlife tracking to gather data on wildlife presence in key wildlife linkage, and engage citizen scientists and advocates. Over the last decade we have monitored fifty 1.5-mile long transects within seven priority linkage areas in southern Arizona and New Mexico; the majority of these located on public lands. This article focuses on our longest monitoring effort located in the Las Ciénegas Wildlife Linkage, using Davidson Canyon transects as case study examples.

Study Area

The Sky Island region is a 70,000-square-mile world biodiversity hotspot (Mittermeier and others 2005), a biological bridge where the temperate Rocky Mountains and Colorado Plateau meet the subtropics, the Sierra Madre Occidental, and the Sonoran and the Chihuahuan Deserts.

Within this biological region, the Las Ciénegas Wildlife Linkage, which connects the Rincon Mountains to the Empire, Whetstone, and Santa Rita Mountains, has been identified as a high-priority wildlife linkage (Arizona Wildlife Linkages Workgroup 2006; Beier, Majka, and Bayless 2006). Sky Island Alliance's work in this corridor began in 2001 when we conducted a 4-month assessment on 10 transects located throughout the area. The results were included in the "Missing Link Report" (also referred to as the Ciénega Creek Corridor), presented to the Bureau of Land Management (Sonoran Institute 2003). Subsequently, Pima County recognized the ecological importance of this area and designated the linkage as a Critical Landscape Connection in the Pima County Sonoran Desert Conservation Plan (2004).

SIA continued this study and has monitored 10 transects consistently between 2002 and 2011 in the Las Ciénegas Wildlife Linkage (fig.1). Transects occur both north and south of Interstate-10; four transects occur within the Las Ciénegas National Conservation Area under Bureau of Land Management jurisdiction.

Davidson Canyon is an ephemeral stream that runs south to north, provides wildlife habitat and water recharge in the Ciénega-Rincon watershed. Its relationship to the perennial Ciénega Creek and endangered species such as the Chiricahua leopard frog (*Rana chiricahuensis*) and gila topminnow (*Poeciliopsis occidentalis occidentalis*) has led to concerns over proposed mining projects in the Santa Rita mountains (Coronado National Forest 2011; Sky Island Alliance 2011). The high and expansive bridge that spans the canyon at Interstate-10 enhances the importance of Davidson Canyon as a wildlife corridor, which is one of the few drainages in the Las Ciénegas Wildlife Linkage that facilitates safe passage of wildlife across Interstate-10. Davidson Canyon also is a direct connector for the Santa Rita Mountains across Scenic Highway 83, making it an integral piece of the Santa Rita-Rincon-Whetstone mountain linkage complex.

There are several recent confirmed sightings of jaguars and ocelots in southeast Arizona (Avila and others *In press*). It is possible that these species are moving north from the Patagonia Mountains to the Santa Rita Mountains, and across Highway 83 utilizing Davison Canyon and the Las Ciénegas Wildlife Linkage to reach large habitat blocks in locations to the east, such as the Whetstone and Dragoon Mountains. Conversely, black bear periodically use the same pathway moving south from the Rincon Mountains to the Santa Ritas (Atwood and others 2011), thereby bolstering the genetic health of a newly

discovered Sonoran population, a population ironically made distinct by its isolation from northern Arizona mountain ranges (Atwood and others 2011).

Methods

The Wildlife Linkages Program track identification and data collection protocol is adapted from Keeping Track, Inc. (Hass and others 2000; Przybyl 2003) to consider regional requirements, like dry tracking conditions in sand and dirt rather than snow. Transects were established in areas most likely to provide evidence of wildlife activity, primarily in sandy washes, dirt roadways, or riparian edges, where there is suitable substrate for tracking. We established strategic 1.5-mile long by 60-foot wide transects in potential linkages, surveyed every 6 weeks by teams of trained volunteers. In aggregate, teams conduct nine surveys per year: two surveys occurring each season, with three surveys occurring in summer to capture data during pre-summer and monsoon conditions.

Volunteers go through a five-day training course in track and sign identification and documentation in the field. Teams of two to four trained trackers are then permanently assigned to one transect, and are provided with datasheets, GPS units, cameras, track identification cards and tracking rulers. A minimum of two trained trackers is required for each survey. A data point is recorded when the tracking team come to consensus about the identification of a track or sign.

Tracking teams survey in early morning, when temperatures are cool, the angle of light refraction is optimal for track visibility and photo-documentation, and nocturnal species tracks are freshest. Tracking surveys conducted later in the day have a lower chance of detecting nocturnal or crepuscular species and a higher chance of detecting diurnal species (Hanson and Hanson, personal communication). In early morning, there is also a higher probability of seeing wildlife tracks that increased human and cattle activity might eliminate during the day. No surveys are conducted during rainfall, due to low visibility of tracks and field safety.

Sky Island Alliance's Wildlife Linkages Program focuses on regional animal focal species categorized as a keystone, umbrella, or indicator species, habitat specialists, or have an unknown or shifting population or distribution. Threatened or endangered species often fit many of these categories. Focal species are plants or animals whose survival needs are also requirements of a healthy ecosystem, therefore making them indicators of ecosystem health (Miller and others 1999). Eight focal species were identified for study: jaguar (*Panthera onca*), ocelot (*Leopardus pardalis*), bobcat (*Lynx rufus*), mountain lion (*Puma concolor*), Mexican gray wolf (*Canis lupus baileyi*), black bear (*Ursus americanus*), white-nosed coati (*Nasua narica*), and western ornate box turtle (*Terrapene ornata*).

Each occurrence of focal species' track or sign is documented on a data collection form, and assigned a data point and photo number. A data point is a sign or set of signs made by a single animal at a single time. Tracks and other sign identified belonging to focal species are photographed with a reference ruler, measured, and information is collected on direction of travel and location. Any non-focal species identified on a survey are recorded with an abundance rating, defined as A (one to five occurrences of sign); B (six to 10 occurrences of sign); and C (>10 occurrences of sign). Additional comments and observations are included; the resulting field notes provide excellent anecdotal information. In addition to track and sign counts we gather baseline information to document changes in transect condition, including evidence of off-road vehicle use, erosion, presence of stock animals, and new barriers to wildlife movement.

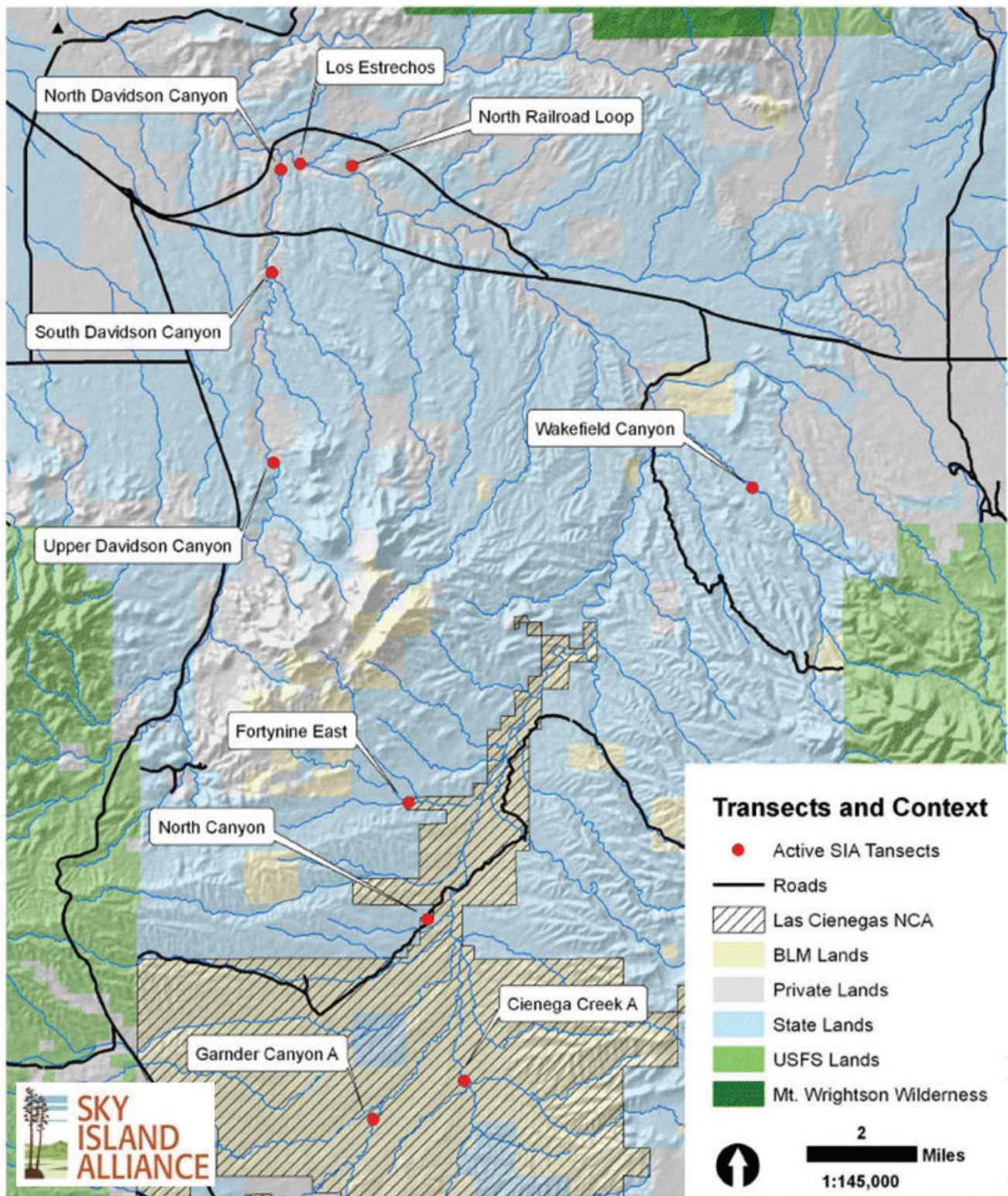


Figure 1—Study area within the Las Cienegas Wildlife Linakge and locations of the ten tracking transects (2002-2011) (map by Nick Deyo).

Results

SIA has conducted over 1,000 track-count surveys and documented over 4,100 records for more than 40 different animal species throughout the region since 2001. In the Las Ciénegas Wildlife Linkage, we have documented 31 species with track and sign surveys throughout the 10 transect study sites between 2002 and 2011 (table 1). The majority are medium to large mammals, including both habitat specialists and generalists. We were successful in identifying tracks or sign for the majority of medium to large mammals known to be present in the area, including all four species of native skunks. We identified lagomorphs to genus, including the eastern and desert cottontail rabbit (*Sylvilagus spp.*), and the antelope and black-tailed jackrabbit (*Lepus spp.*).

We compared transect results using the proportion of surveys with track and sign detection of similar large and medium sized mammal species (fig. 2). We categorized these by obligate carnivores: mountain lion and bobcat; omnivores: black bear and white-nosed coati; and herbivores: mule deer (*Odocoileus hemionus*), white-tail deer (*O. virginianus*) and collared peccary (*Tayassu tajacu*). Detection of ungulate track and sign in these transects appeared to be lower than in the more northern transects in the study area, possibly due to these species preferring open habitat found away from Cienega Creek.

The two transects that make up the 3-mile stretch of Davison Canyon where it flows underneath Interstate 10 have been monitored simultaneously between 2002 and 2006. We documented 24 species here during the 4-year period (table 1). We compared North and South Davidson Canyon transects for four of these species: black bear, bobcat, white-nosed coati, and mountain lion (fig. 3). There is a marked difference between the two transects for both mountain lion and white-nosed coati, although we must acknowledge that this could be a factor of observer bias or occasional track detectability changes caused by substrate or weather.

One noteworthy result from this study was that black bear track and sign increased dramatically during the months of April and September-October across all transects. Although the sample size was relatively small, all black bear tracks documented in North and South Davison Canyon transects during this period showed upstream travel (north to south). This is consistent with Atwood's finding that individuals from a northern population periodically disperse to a genetically distinct population of black bears found south of Interstate 10 (Atwood and others 2001).

Applying Tracking to Conservation

Protected wildlife linkages are the future of sustainable wildlife conservation and rural landscape protection. Over 250 dedicated citizens have participated in our program collecting information and advocating for wildlife movement in the Sky Island region. One of the most impressive successes out of the decade of wildlife monitoring at Sky Island Alliance is the shift in perception about wildlife corridors and landscape level planning by collaborating agencies and stakeholders.

We have successfully applied the resulting species presence information to land-use policy and permanent land conservation, incorporating wildlife data and linkage priorities into the Pima County Sonoran Desert Conservation Plan (2004) and the Santa Cruz County Comprehensive Plan (2005). These results also informed the 2006 Arizona Wildlife Linkages Assessment and the 2012 Pima County Wildlife Connectivity Assessment, two comprehensive mapping projects that identify at-risk wildlife corridors and contribute recommendations for transportation planners and engineers, created through the Arizona

Table 1—Species documented by tracks and sign on Las Ciénegas Linkage transects (n = 10) between 2002-2011.

Common name	Scientific name
Badger	<i>Taxidea taxus</i>
Black bear ^a	<i>Ursus americanus</i>
Bobcat ^a	<i>Lynx rufus</i>
Collared peccary ^a	<i>Tayassu tajacu</i>
Cottontail rabbit ^a	<i>Sylvilagus spp.</i>
Coyote ^a	<i>Canis latrans</i>
Domestic cat ^a	<i>Felis catus</i>
Domestic cattle ^a	<i>Bos taurus</i>
Domestic dog ^a	<i>Canis lupus familiaris</i>
Domestic horse ^a	<i>Equus caballus</i>
Gambel's quail ^a	<i>Callipepla gambelii</i>
Gila monster ^a	<i>Heloderma suspectum</i>
Gray fox ^a	<i>Urocyon cinereoargenteus</i>
Great blue heron	<i>Ardea herodias</i>
Hooded skunk ^a	<i>Mephitis macroura</i>
Jackrabbit ^a	<i>Lepus spp.</i>
Kangaroo rat	<i>Dipodomys spp.</i>
Mountain lion ^a	<i>Puma concolor</i>
Mourning dove	<i>Zenaida macroura</i>
Mule deer ^a	<i>Odocoileus hemionus</i>
Ornate box turtle	<i>Terrapene ornata</i>
Raccoon ^a	<i>Procyon lotor</i>
Ringtail ^a	<i>Bassariscus astutus</i>
Roadrunner ^a	<i>Geococcyx californianus</i>
Sonoran desert tortoise	<i>Gopherus morafkai</i>
Striped skunk ^a	<i>Mephitis mephitis</i>
Western hognose skunk ^a	<i>Conepatus mesoleucus</i>
Western spotted skunk ^a	<i>Spilogale gracilis</i>
White-nosed coati ^a	<i>Nasua narica</i>
White-tailed deer ^a	<i>Odocoileus virginianus</i>
Wild turkey	<i>Meleagris gallopavo</i>

^a Species documented in Davidson Canyon.

Wildlife Linkages Workgroup (Arizona Wildlife Linkages Workgroup 2006; Arizona Game and Fish Department 2012).

Wildlife monitoring data and volunteer advocacy have been instrumental in documenting Wilderness quality lands and providing momentum to efforts to permanently protect core habitat as designated Wilderness. In addition, with wildlife tracking information we have provided strong, accurate responses to transportation infrastructure, mining and energy development projects that threaten to impact key wildlife blocks and adversely affect associated wildlife linkages. For example, we provided strong evidence to defeat a proposed amendment to the 2040 Regional Transportation Plan that called for widening Scenic Highway 83 from two to four lanes. This project would have significantly damaged the integrity of the Las Ciénegas Wildlife Linkage without extensive wildlife crossing structures in place to mitigate the loss of connectivity and allow animals to cross the highway safely.

Three wildlife crossing structures, including the second wildlife overpass to be constructed in Arizona, were recently approved as part of a needed expansion of State Route (SR) 77 in Oro Valley. Our track and sign monitoring data, the Arizona Wildlife Linkages Assessment (2006) and detailed corridor modeling (Beier, Garding and Majka 2006) in the Catalina-Tortolita mountain wildlife linkage supported this decision. Similarly, in December 2011, 10 years after tracking volunteers first put feet to the ground, a new project on SR86 near Kitt Peak proposed by the Tohono O'Odham Nation and informed by the Arizona Wildlife Linkages Assessment gained final approval

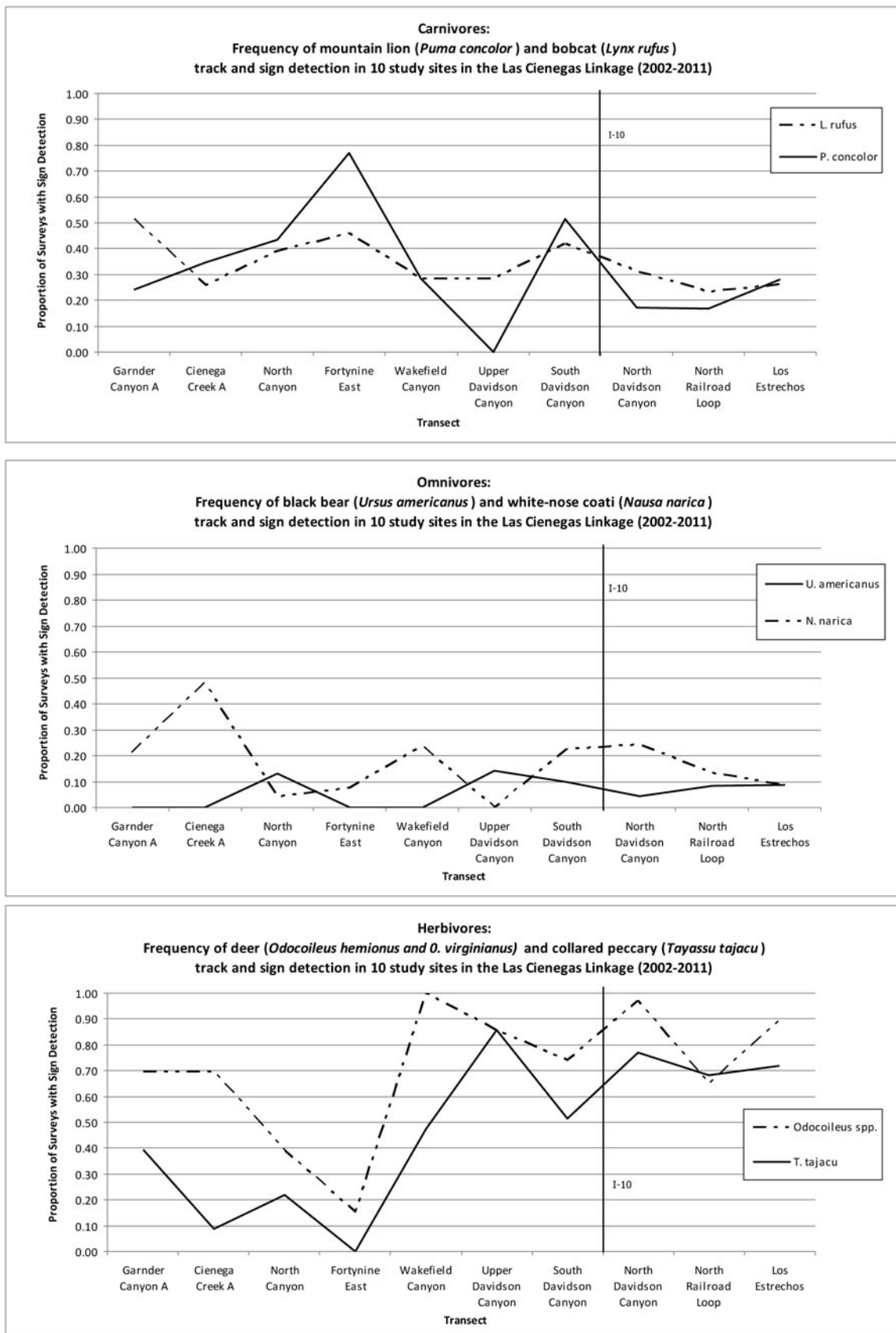


Figure 2—A comparison of the frequency of track and sign detection in 10 study sites in the Las Cienegas Wildlife Linkage for select carnivore, omnivore, and herbivore species (2002-2011). The location of Interstate-10 is indicated on each graph, and transects are arranged left to right as south to north to provide a spatial illustration. The southernmost transects (Gardner Canyon A, Ciénega Creek A, North Canyon, and Forty-nine East) occur within the Las Ciénegas National Conservation area.

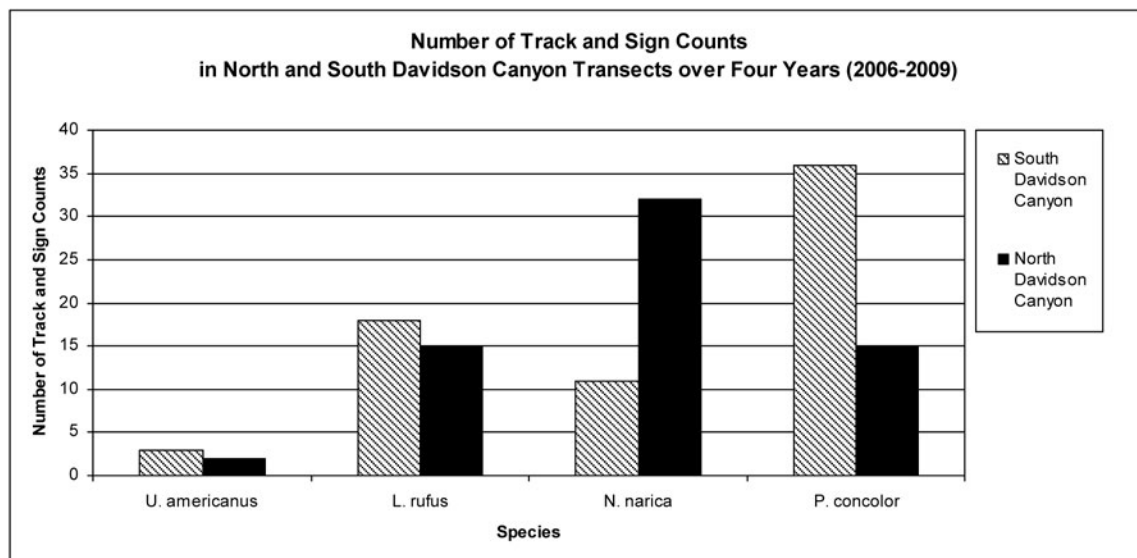


Figure 3—Number of track and sign counts documented on South and North Davidson Canyon transects over a period of 4 years (2006-2009)

for Pima County Regional Transportation Authority. This project will include two wildlife underpasses and a vegetated wildlife overpass. The SR77 wildlife-crossing project, scheduled to break ground in 2013, is serving as a model for similar projects in Pima County. As population and transportation needs increase, these critical wildlife connections will become more necessary. There is continued value for public engagement, increased public understanding of the intrinsic value of wildlife and their habitats, and the information gathered that track and sign monitoring provides.

Conclusions

Long term tracking results have provided useful information about the presence and movement of wildlife in the Las Ciénegas Wildlife Linkage and Davidson Canyon. Track and sign monitoring provides an excellent opportunity for cost-effective, publicly engaging, data collection that has strong implications for conservation. It serves as both an advocacy tool as well as a scientific method of determining wildlife presence. We recommend using track and sign identification for landscape scale wildlife monitoring efforts as a non-invasive alternative or to provide supplemental data where technicians or volunteers are conducting field investigations and the project may benefit from these additional observations.

Acknowledgments

This program and its success would not be possible without the dedication and skill of our volunteer trackers. We would like to thank our tracking instructors over the years: Steve Bless, Janay Brun, Jack Childs, Jonathan and Roseann Hanson, Christine Hass, Lisa Haynes, Aletris Neils, Harley Shaw, Sheridan Stone, and Cynthia Wolf. Kristen Campbell, Jill Kelleman, Melissa Lambertson, Louise Misztal, Christine St. Onge, and Alex Smith assisted with data synthesis and editing. Dr. David Bygott and Dr. Jeanette Hanby provided useful reviews.

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Black Bear Population and Connectivity in the Sky Islands of Mexico and the United States

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Abstract—The Sky Island region is a mountainous region surrounded by grasslands, deserts and intermountain valleys, located between Mexico and the United States. However, different land management and human impact can have an effect on its wildlife populations. Currently, the border wall poses an immediate threat to the survival of black bears (*Ursus americanus*), considered an endangered species in Mexico. Our aim was to determine the conservation status of black bears in the Sierra San Luis as affected by the border fence. We determined population size through camera traps and radio-telemetry, and modeled population occupancy using PRESENCE. We documented a bear population with more than 500 individuals. Surveys along the border failed to detect bears crossing it, but we identified linkages between the two countries, which shall be important for future landscape planning. Increased vehicular traffic, migration, and drug traffic have a negative effect on bear populations, exacerbated by an increase in anthropogenic activities resulting from the construction and maintenance of the border wall. We recommend modifications to the structure of the border wall, and to increase wildlife monitoring by the United States authorities in order to reduce the potential impacts that this structure has on black bears and other wildlife populations.

Introduction

The black bear is the largest carnivore and the only *Ursid* species present in Mexico (Hall 1981; Doan-Crider and Hellgren 1996). Historically, its distribution included the States of Sonora, Chihuahua, Coahuila, Tamaulipas, Durango, Zacatecas, Sinaloa, San Luis Potosí, Jalisco, Nayarit, and Aguascalientes (Leopold 1959; Baker and Greer 1962; Hall 1981; Delfín-Alfonso and others 2011). However, during the 20th century, black bears were hunted, captured, and poisoned as a means of protection, because they were perceived as a threat to livestock and crops; the bears were harvested commercially for their skins and fat (Baker 1956; Leopold 1959; Medellín and others 2005). These actions caused to loss of 80% of their range (SEMARNAP-INE 1999).

Black bears currently are classified as endangered in most of its distribution in Mexico (SEMARNAP-INE 1999; SEMARNAT 2010). Although harvesting and hunting is prohibited (CITES 2009) and there are programs for black bear conservation (PROCER; CONANP 20011), their populations are at risk because of habitat loss, fragmentation (Leopold 1959; Pelton 1982; Robins and others 2004), and other human activities (Costello and others 2001).

The populations in the Sierra Madre Oriental has increased due to protection through the implementation of Management Units for Wildlife Conservation (UMAs) and Natural Protected Areas. These populations are more abundant compared with populations in the Sierra Madre Occidental (Doan-Crider 1995a; López-González and Lara-Díaz 2010).

In the Northern part of the Sierra Madre Occidental (SMO), bears remain in a naturally fragmented habitat, the Sky Islands, (Varas 2010; Delfín-Alfonso and others, in press) in Mountain ranges as San Luis, Los Ajos, El Tigre, Sierra Azul, La Elenita, Buenos Aires, and El Gato (Gallo and Garza 2002). However, information about their population status is poor. Sierra de San Luis may be the “source population” of individuals to the rest of the Sky Islands in Mexico and one of the primary connectivity areas with the populations in United States, therefore, contributing to the recovery of black bears in Mexico (Lara-Díaz 2010; López González and Lara-Díaz 2010; Varas 2010). Additionally, in the SMO and Sky Islands, there are immediate threats that can bring negative effects from short- to long-term for black bear populations (List 2007) mainly because of the construction and operations of the border fence between Mexico and the United States (Public Law 109-367 2006), and the expansion in two additional lanes of Federal Highway No. 2 (Agua Prieta-Janos) located within 5 km south of the border.

Black bears must maintain their mobility and their ability to grow and maintain viable populations if they are to survive in a highly fragmented landscape (Meffe and Carroll 1997; Crooks 2002; Duffy 2002; List 2007). Given the uncertain status of black bears in the Sky Islands, however, it becomes necessary to establish conservation and habitat management actions, through a solid base of biological knowledge of the species, in order to give viability to their populations in the long-term (Rogers 1993; Robins and others 2004). Our

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objective was to generate information on the current status of the black bear population in Sierra de San Luis and identify key areas of connectivity between the two countries.

Study Area

The Sierra de San Luis (SSL; fig. 1) is located at the NE of Sonora (31° 11' N, 108° 56' W) within the Sky Islands region, which consists of mountains that are isolated from one another by large extensions of desert and grasslands (Onorato et al. 2003; The Wildlands Project 2000). The area is also under the influence of the SMO, the Rocky Mountains, and the Chihuahuan and Sonoran deserts (Ponce-Guevara and others 2005).

The SSL is characterized by a dry temperature with summer rains. The average temperature in the summer is between 18 °C and 7 °C in winter (INEGI 1973). The average annual precipitation ranges from 450 mm (~1500 m) to 700 mm (~2500 m; Íñiguez et al. 2005). July receives the highest rainfall (86 to 106 mm) and the lowest precipitation occurs in May (2.7 to 3.2 mm; INEGI, 1973). The elevation of the locations ranges from 1,500 to 1800 m (Rodríguez-Martínez and others 2008). The hydrogeology is characterized by the presence of the Cajon Bonito River and several artificial water bodies and puddles (Rodríguez-Martínez and others 2008).

The dominant vegetation consists of grasslands and scrub. The representative species are the palmilla (*Nolina microcarpa*), Engelmann's nopal (*Opuntia pheacantha*), maguey (*Agave palmeri*) and sotol (*Dasyliion wheeleri*). There are also areas with gallery forests

dominated by aspen (*Populus* sp.) and in some areas juniper-oak or huizachal-oak associations can be found (Rodríguez-Martínez and others 2008).

Methods

Population Size

To estimate the black bear population size in SSL, we placed camera traps (WildView5®) in two sites from July to August 2010—23 camera traps in El Pinito Ranch and 29 camera traps in Los Ojos Ranch. The camera traps were placed on roads identified as fauna passages and were separated about 1 km. They were placed with S-N orientation. As bait, we placed in front of each camera a combination of sardines in tomato sauce, a mixture of oat-corn, and finally a vanilla extract sprayed with an atomizer into the above mixture. The camera traps were programmed to record the date and time (military format) and to take three successive photographic events every minute if they were activated.

Black bears in the photographic records were identified at the individual level through a comparative analysis of opinions where five observers discriminated individuals between the images obtained independently. Unusable photographs to distinguish individuals were eliminated, producing a consensus by which was established the average number of individuals; this approach has been used successfully in other studies (Kelly and others 2008). With these results, we constructed a capture-recapture history for each individual generating

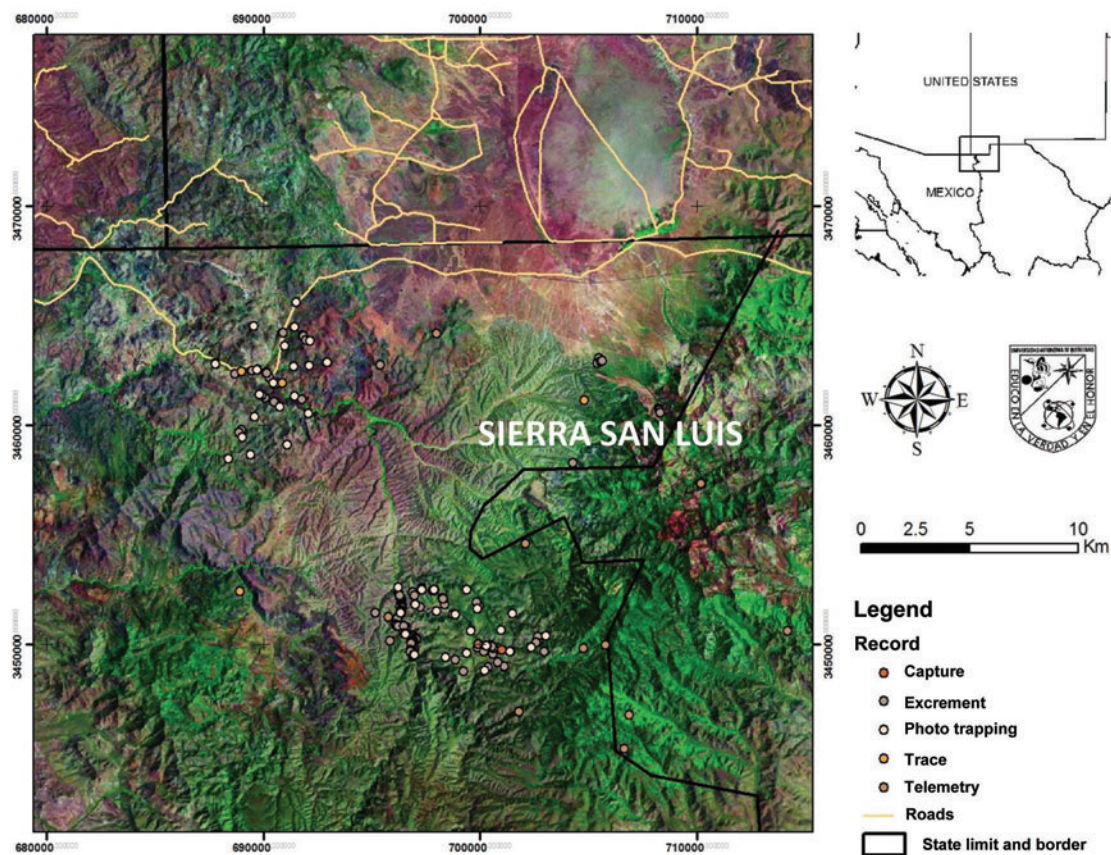


Figure 1—Study area and records of Black Bear in Sierra de San Luis, Sonora, México.

a database of presence (1) or absence (0) according to the sampling days.

The abundance was estimated with the MARK 6.0 program (White 2008), using the Capture tool, considering the assumptions of a closed population through the appropriate model of capture probability. We calculated the effective sample area generating a buffer surrounding each camera, using the average home range for black bear in SSL (32.33 km²; López-González and Lara-Díaz 2010), in the ArcMap ver. 9.3 program (ESRI 2008), with the “buffer” tool, and avoiding overlapping areas. The final area was calculated using the extension Xtools Pro (ver. 5.3) for ArcMap. For black bear density, the abundance parameter was divided by the effective sampling area, being reported as number of individuals per km². Finally, the density data (individuals/km²) was extrapolated to the SSL area.

Occupancy and Connectivity

Black bear records obtained during the study (including photographs, feces, capture, telemetry, traces) were used to generate the occupancy probability of the species in the study area, using the PRESENCE ver. 3.0 program (Hines 2006) and following the protocol established by Donovan and Hines (2007), which considers a single species, in a season of sampling, with covariates associated to the sites.

We considered an area of 26,307 km² (fig. 2) for calculating the occupancy probability. With the help to GIS, we divided the area into

a grid with sampling units of 1 km each. Each sampling unit visited, where we placed a camera trap or searched for traces, was associated to black bear presence or absence. Sampling units that were not visited during the monitoring events were listed with a dash (-) because it was unknown if the species was present or not. Thus, the detection history of the species was generated. Additionally, we generated a matrix of covariates associated with each sample unit: elevation (USGS 1993), Normalized Difference Vegetation Index (NDVI; Earth Observatory 2010), roughness (USGS 2001) and slope (USGS 2001), all of them important variables for black bear presence (Moreno 2008).

To associate the covariates of elevation, roughness, and slope to sample units, we used the ArcView 3.2 program (ESRI 1999) where each covariate is represented by a raster layer, and they were clipped to the study area through the Spatial Analyst extension (ver. 1.1). The information of each layer was added to the grid of the study area through the Get Grid Value extension 2 (Davies 2000). Moreover, the NDVI values for each of the sample units was generated by a LANDSAT satellite image using Image Analysis extension (Pinedo and Pinedo 2006) for Arcview 3.2 program (ESRI 1999). The covariates were normalized to be introduced to the program (Mackenzie and others 2003).

Based on the black bear detection matrix and the covariates matrix, we generated probability models with the PRESENCE program (Hines 2006). Each model considered the occupancy probability and detection probability associated with one or more covariates, also considering

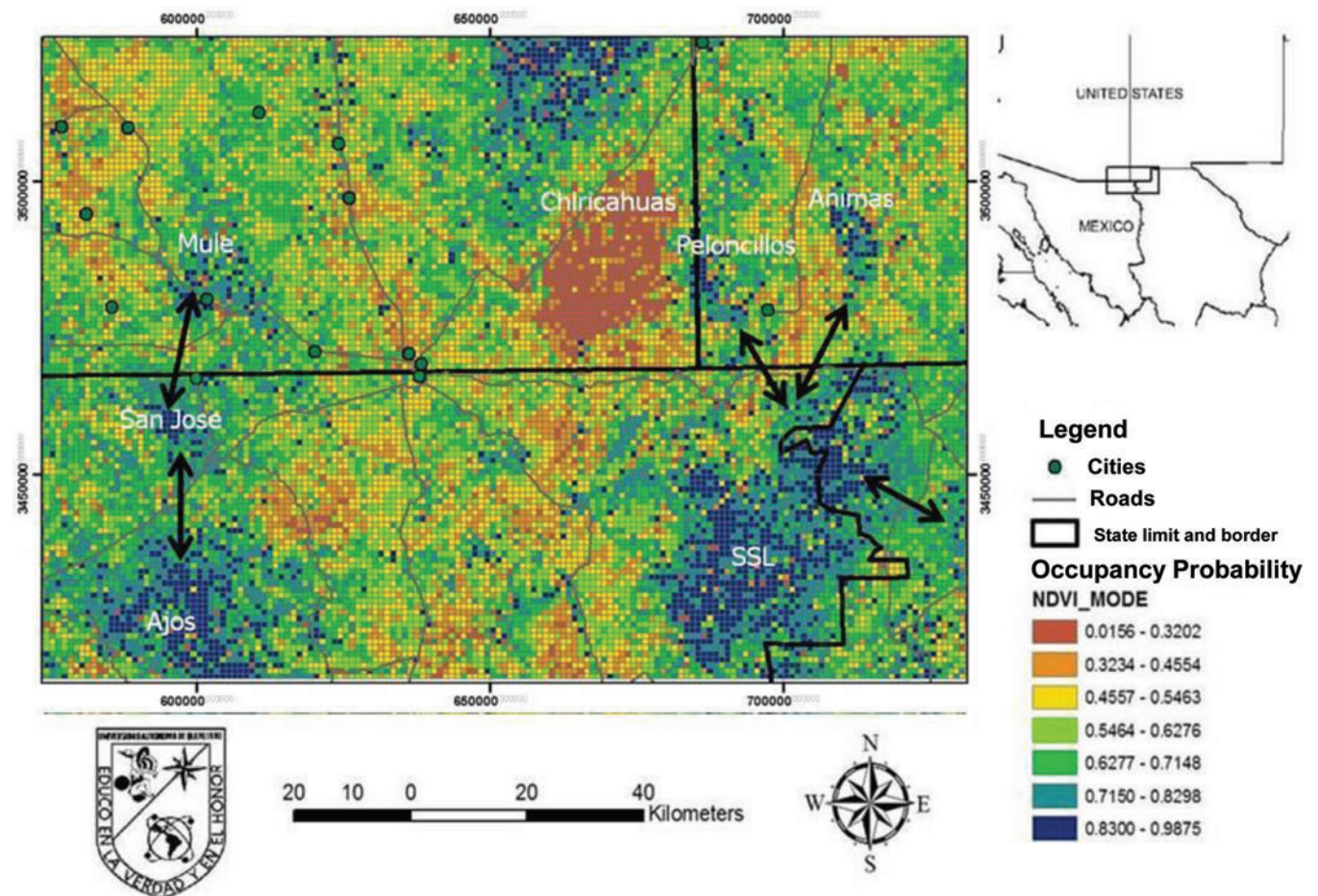


Figure 2—Occupancy probability of black bear (*Ursus americanus*) in the border region of Sonora and Chihuahua, México.

a constant covariate and a time-dependent covariate (Donovan and Hines 2007). Thus, we generated 1,056 models, given by the possible combinations among covariates. The best model to explain the occupancy and detection probabilities was selected through the lower Akaike Information Criteria (AIC) (King and others 2007).

Once we obtained the best model and given the occupancy probabilities per sample unit of 1 km² (obtained by the program), these probabilities were associated with a space-map to get a representative image of the occupancy probability distribution of black bears in the study area. This was achieved by using the ArcMap 9.3 program (ESRI, 2008) considering areas with the highest occupancy probability and greater coverage, which are the more likely for having connectivity between areas.

Results

Population Size

We obtained a total 30 different individuals in El Pinito Ranch and 18 different individuals in Los Ojos Ranch with a sampling effort of 4,413 camera-days. The abundance was estimated at 34 and 24 individuals, respectively. El Pinito Ranch had a higher density (0.322 individual/km²) compared to Los Ojos Ranch (0.161 individual/km²; table 1).

The SSL has an approximate area of 2,300 km² including 50 km south of the international border. Extrapolating the estimated average density obtained through our study, we believe there may be a black bear population of about 550 individuals; however, this population estimate may be reduced depending on management and predator control being carried out by different ranches in the area.

Occupancy and Connectivity

In the period from June 23 to November 3, 2010, we obtained a total of 209 records that documented the black bear presence. These records included 149 feces, six sets of traces, 41 camera-trap stations, four captures and 10 telemetry locations (fig. 1).

The best occupancy probability model (AIC = 390.37) was the one associated with the occupancy probability (*psi*) to NDVI, and the detection probability (*p*) to time. According to this model, the most likely area where black bears can be found is SSL, whose connectivity to the United States occurs in two main points from Puerto de San Luis (Mexico) to Animas Mountains (United States) and from the west of the SSL to Peloncillo Mountains (United States), eventually connecting to the Chiricahua Mountains (fig. 2). The region of the Sierra de Enmedio, in the Chihuahua State, hardly connects to the north with appropriate areas for the black bear, making it likely that individuals migrate north along the Sierra de San Luis. The other connectivity passage to the United States for black bear populations in the Sky Islands is the north part of the Sierra de Ajos (Mexico) through the Sierra San José (Mexico) and connecting with Mule Mountains (United States; fig. 2).

Discussion and Conclusions

The black bear population in Sierra de San Luis seems to be the largest in Sonora and Chihuahua. The abundance and density data obtained, as well as indirect records, have been higher compared with mountain ranges as Ajos, El Tigre and La Madera in México, where the densities have been estimated to be less than 0.05 individuals/km² (Lara-Díaz 2010).

The monitoring carried out during the study period shows a potential increase in black bear population in SSL relative to previous years (Sierra Corona and others 2005; Rodríguez and others 2008). This increase allows this population to be a source of individuals to other populations in the region. This result may be the outcome of multiple management strategies in the region, with areas dedicated to conservation with no hunting and a limited predator control. However, we must consider that some ranches still continue to implement measures against predators, and, therefore, the habitat for the black bears may be less suitable. Consequently the population size in SSL may be smaller.

In terms of connectivity, black bears should not have restrictions to continue crossing the border on the existing vehicle barriers. We believe that asking for modifications to the construction structure and the placing of it would be unrealistic. However, we can recommend to remove or modify the barbed wire that makes up the lower portion of the barrier and to raise the final strand; these simple actions can facilitate transition of young or juvenile black bears. Adults seem to have no problem crossing because they can easily climb the vehicle barriers.

It is important to reduce people and vehicular traffic in the areas identified as priority for possible connectivity of black bear populations from the two countries. If possible, increasing remote monitoring techniques (cameras and unmanned aerial vehicles) by the border agents would help the bears to continue crossing in these priority areas. Likewise, implementation of crossing points for wildlife with the expansion of Federal Highway No. 2 should reduce the number of collisions and, thus, would increase the probability that a black bear makes it to the border and across it. If black bear populations are to survive in the Sky Islands of the Northwest of Mexico, it is essential to maintain the connectivity sites from SSL and Sierra de Ajos to the United States.

Although the black bear population in SSL is reproducing and has recently increased, individuals of this population are not sufficient to reevaluate the endangered category in the region. Black bears are still widely pursued under the belief that they seriously affect production activities in the area. Finally, continuous monitoring of black bears populations in the Sky Islands is essential to assess the species status in the medium and long-term, and it is also essential to develop strategies for conservation and appropriate management.

Table 1—Abundance and density of black bear (*Ursus americanus*) at two study sites in the Sierra de San Luis, Sonora, México.

Site	Abundance (individuals)	S. E.	Interval (95% confidence)	Effective Sampling area (km ²)	Density (Ind./km ²)	Density S. E.t
El Pinito	34	3.98	31 a 50 individuals	105.600	0.322	0.387
Los Ojos	24	4.51	20 a 40 individuals	149.340	0.161	0.369

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Inventory of Terrestrial Mammals in the Rincon Mountains Using Camera Traps

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Abstract— The Sky Island region of the southwestern United States and northwestern Mexico is well-known for its diversity of mammals, including endemic species and species representing several different biogeographic provinces. Camera trap studies have provided important insight into mammalian distribution and diversity in the Sky Islands in recent years, but few studies have attempted systematic inventories of one or more mountain ranges with a repeatable, randomized study design. We surveyed medium and large terrestrial mammals of the Rincon Mountains within Saguaro National Park, and compared the results with previous surveys of the Rincons. We sampled in random locations in four elevational strata from May 2011 through April 2012. We detected 23 native species of mammals and estimated species richness to be 24.8 species. We failed to detect four native species documented by other methods during 1999-2012, as well as five species (bighorn sheep, grizzly bear, jaguar, gray wolf, and North American porcupine) documented during 1900-1999 that may be extirpated from the Rincons. Advances in camera trap technology, as well as an expanding use of this technology by educators and the public, suggest this method has the potential to be a cost-effective and reliable method for both inventory and long-term monitoring of terrestrial mammals of Sky Island region.

Introduction

The Sky Island region of the southwestern United States and northwestern Mexico is known for exceptional biological diversity, including species from the Sierra Madre, Rocky Mountain, Sonoran Desert, and Chihuahuan Desert biogeographic provinces (Swann and others 2005) and as many as 15 mammals on the edges of their biogeographic range (Warshall 1995). Southeastern Arizona, in particular, has been characterized as possessing the greatest mammalian diversity in North America north of Mexico (Turner and others 1995) including species with more northern affinities such as black bears (*Ursus americanus*) and tropical species such as ocelots (*Leopardus pardalis*), jaguars (*Panthera onca*), coatis (*Nasua narica*), and others. Several high profile species have been extirpated, including grizzly bear (*Ursus arctos*) and Mexican gray wolf (*Canis lupus*), while others such as jaguars, ocelot, bighorn sheep (*Ovis canadensis*), and pronghorn (*Antilocapra americana*) are considered highly vulnerable.

Species inventories, or verified lists of species that occur in a particular area, have value for many reasons (Sidner and Stone 2005) including studies of biogeography (Newmark 1995; Lomolino and others 1989), determining environmental change (McDonald and Brown 1992), and determining status of sensitive species. In addition, repeated inventories may provide data for monitoring long-term changes in plant and animal communities if conducted

using a randomized, repeatable study design that allows estimates to be made of measures such as native species richness (the number of native species that occur in an area). Loss of biodiversity is one of the world's greatest environmental concerns (Wilson 1988) and detecting changes in diversity can be accomplished through repeated inventories conducted in a framework for drawing inference about variation in species richness over time (Nichols and others 2011).

Because of the significance of the Sky Island region, taxonomic inventories of its individual mountain ranges have been conducted for over a century (Swarth 1904) and remain a principal focus of biologists to this day. Recent inventories of reptiles (Fleisch and others 2010), vascular plants (Van Devander and Reina 2005; Bowers and McLaughlin 1996), and other taxonomic groups exist for many prominent Sky Islands but inventories of mammals have generally lagged behind (Koprowski and others 2005). Although older surveys exist for selected ranges (Cahalane 1939; Hoffmeister and Goodpasture 1954; Lange 1960) mammals as a group are generally less well-studied and a recent paper (Koprowski and others 2005) identified a "dearth of data" on the mammals of the region. In addition, although medium and large mammals have a higher profile with the public than smaller mammals and bats, past inventories (Hoffmeister and Goodpasture 1954) have tended to focus on the latter groups because more of those species can be easily captured using a single method such as live-trapping and mist-netting. Inventory methods for larger mammals include collection of specimens by trapping and shooting, but these techniques are generally discouraged today. Other methods include use of sightings, tracks, and other sign, but these approaches have the disadvantage of not always being verifiable by other researchers. In addition, the probability of detection varies widely among species, habitats, and time. Many mammals are very elusive, rare, or both and may be present at a site but not detected during even a multi-year study (Tobler and others 2008).

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Infrared-triggered cameras, also called camera-traps, represent an important newer technology in mammal studies and are now used widely to study animal behavior (Bridges and Noss 2011), estimate abundance (Karanth and others 2011), and inventory mammals and monitor communities (Tobler and others 2008; O'Brien and others 2011). Camera-traps have a great advantage over observational studies in that they provide a record of each species, similar to a voucher specimen, which can be viewed by independent observers. They are relatively inexpensive to operate and can be left alone to gather data for long periods. Most importantly, camera-traps provide data that can be used to estimate the detection probability of individual species in different habitats, camera settings, time periods, and other factors that are known to influence detectability (O'Connell and others 2006; O'Brien and others 2011). In recent years, camera-traps have made a significant contribution to our knowledge of jaguars, ocelots, and other tropical cats of the Sky Island region (McCain and Childs 2008) while providing important information for conservation and management of mammals in small reserves (Crooks and others 2008; Swann and others 2010). However, most of these studies were in a relatively small area over a short time-frame.

We conducted an inventory of medium and large mammals in both districts of Saguaro National Park from May 2011 through June 2012. Our goals were to use a randomized study design to collect photos of all mammals that could be detected by our cameras, and to use these data to estimate species richness, as well as detectability and percent occupancy for common species. In addition to providing baseline monitoring data, we wanted to compare our results with a similar study during 1999–2005 (Swann and Powell 2006) and historic data (Davis and Sidner 1992; Swann 2011) to determine if species richness or distribution has changed significantly during the past decade and past century. Finally, we hoped to use photographs to interpret wildlife in the park through social media outlets while also providing opportunities for service learning and citizen science. Here, we present partial data (May 2011–March 2012) for the park's Rincon Mountain District.

Study Site

Saguaro National Park is located in Pima County, Arizona, and consists of two disjunct districts separated by the city of Tucson (fig. 1). The park includes 37,005 ha, of which 28,694 ha (78%) are designated Wilderness. The Rincon Mountain District covers a large portion of the Rincon Mountains, a northern Sky Island range adjacent and biologically connected to the Santa Catalina Mountains. The portion of the Rincon Mountains within the park ranges in elevation from 814–2,614 m. Biotic communities include Sonoran desertscrub, semi-desert grassland, oak savannah, oak pine-oak forest and woodland, and mixed conifer forest. The Rincon Mountains also contain riparian forest and riparian woodland in canyon bottoms, scattered wet and dry meadows at higher elevations, and perennial springs and spring-fed rock pools (*tinajas*).

Methods

We used a stratified random design with four elevational strata: 814–914 m (hereafter “low elevation”), 914–1,524 m (“low-medium”), 1,524–2,134 m (“medium-high”), and 2,134–2,641 m (“high elevation”) (fig. 2). Previous studies (Davis and Sidner 1992; Swann and Powell 2006) suggested that mammal distribution in the Rincon Mountains varies among these strata, which may be associated with differences in soil type, vegetation, and climate. We divided the park into 1-km plots, deleting any that were >50% outside the park boundary and then randomly selected 15 plots (from a total of 60 plots). If a selected plot included two strata, it was assigned to the strata with the greatest amount of area. We established a minimum distance of 200 m between points.

Within in each plot we placed four Cuddeback Capture camera-traps (Non Typical Inc., Green Bay, Wisconsin). We set cameras at four random points generated for each plot but occasionally used an alternative random point if we determined that a point was not safe

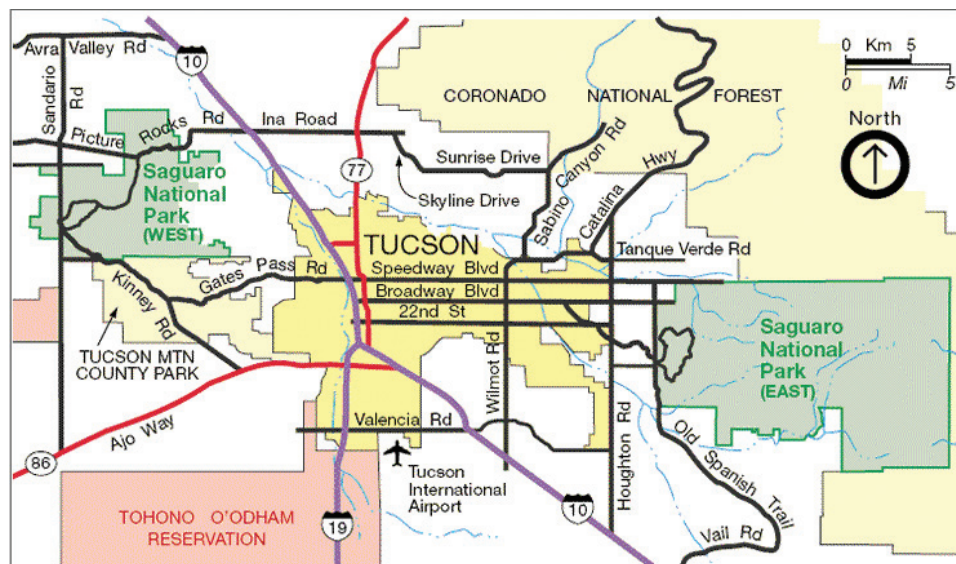
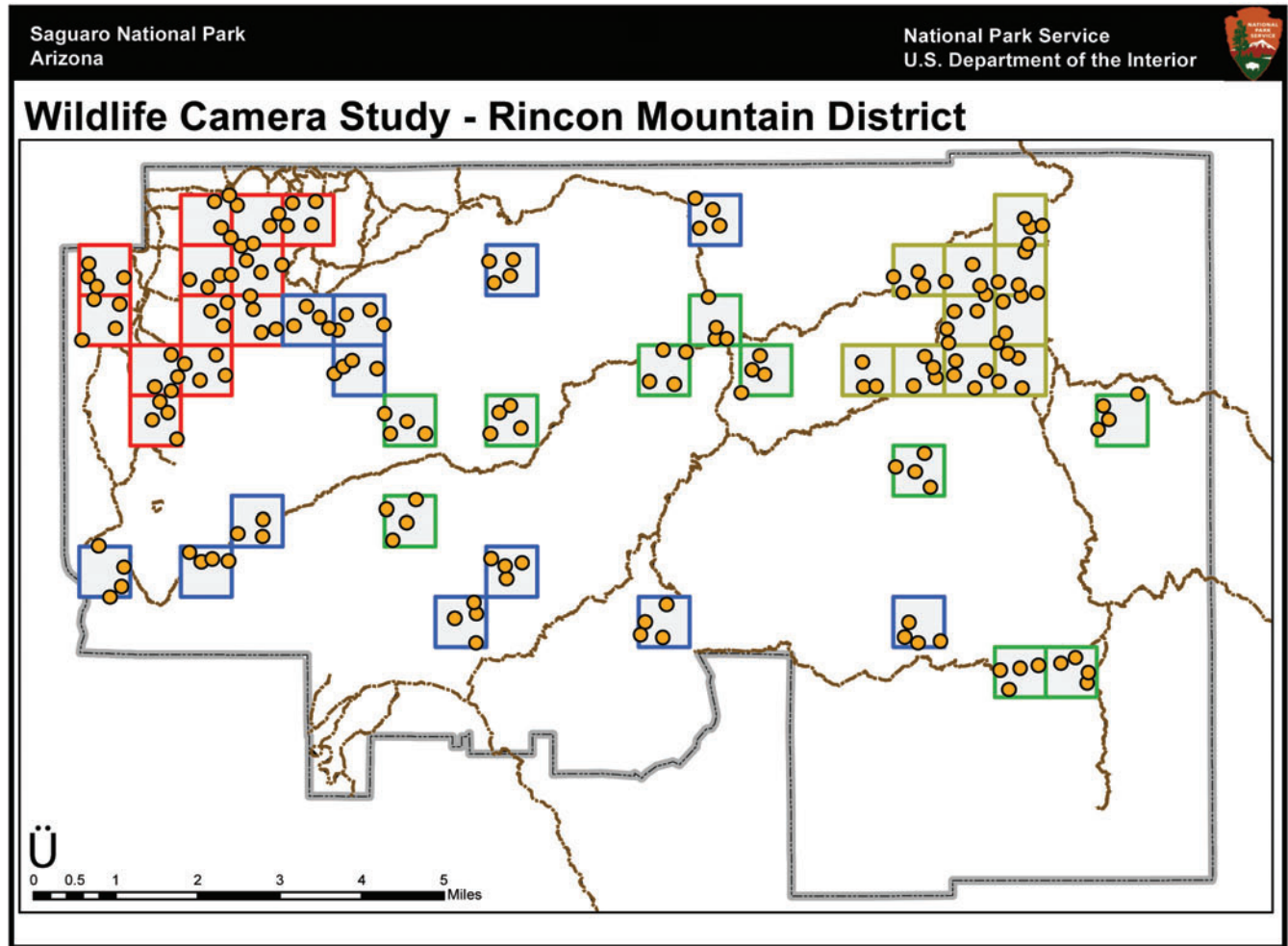


Figure 1—Location map for the Rincon Mountains, east of Tucson, Arizona.



Produced by Nicholas Perkins, GIS Technician Data Source: Saguaro National Park

April, 2012

Figure 2—Study design for camera trap placement in Rincon Mountain District of Saguaro National Park. Four camera traps were placed randomly in each randomly located plot for 6 weeks, with all four strata being sampled from May 2011-March 2012.

for technicians to place a camera (e.g., on a cliff). We navigated to each point using a Garmin GPSmap 76 GPS unit (Garmin International, Olathe, Kansas) and recorded the actual camera location. We set cameras as close to the random point as possible (within 20 m), choosing the closest location that had a sufficiently open field of view to provide the potential to detect an animal if it was present. We made an effort to reduce technician bias in setting cameras through training, but we suspect that some bias on this small scale (e.g., setting cameras where a scat was present) crept in. We set cameras 30-60 cm above ground to detect both larger as well as relatively small mammals, although ground height typically varied within the detection zone. We targeted all terrestrial mammals that were squirrel-sized or larger (>80 g), except for nocturnal rodents and pocket gophers due to the difficulty in identifying them to species level. We did not provide bait or any attractants.

We left cameras in place for 6 weeks. We typically kept two plots active in each of the four strata (total of 32 cameras), although this routine was altered by an extreme fire danger closure of Saguaro National Park in June 2011, a major event (the BioBlitz) in October 2011, and by occasional weather or logistical concerns. We checked plots at least once (but typically twice) during each 6-week interval to

change batteries and verify that cameras were working properly. On each visit we replaced the camera memory card and also downloaded photos and viewed them in the field using a MP3 player.

We downloaded memory cards back in the office and placed photos in digital computer folders arranged by location and named by camera placement date and a unique camera ID. We examined each photo and identified all mammals to species. We independently confirmed all identifications using local experts and sent questionable identifications to taxonomic specialists. We entered all photo data in Excel spreadsheets using a separate spreadsheet for every camera location. We independently checked all data entry. To organize and analyze photo data, we created a file geodatabase with shapefiles for study plots, random points, active camera locations, and other information associated with each camera location. For statistical analysis, we imported a master Excel file that contained all photo records into a GIS (Arcmap) project and added attributes such as geographic coordinates and plot name, and then summarized the records by species to identify misspellings and other errors. We used ArcGIS-based models created for the project to build tables summarizing photo records of species by district and strata.

To calculate species richness of native mammals, we converted these tables to binary data, and used the species richness program EstimateS (<http://viceroy.eeb.uconn.edu/EstimateS>) that computes a variety of biodiversity functions, estimators, and indices for biotic sampling data (Colwell and others 2012). We used the Jack1 estimator in EstimateS; Jackknife estimators perform well when there is heterogeneity in capture probabilities among species as would be expected with camera-traps and past studies have indicated that Jack1 provides the most reliable estimates for large number of camera nights (Tobler and others 2008). For purposes of species richness estimation, we assumed that Abert squirrels (*Sciurus aberti*), which were introduced into the Santa Catalina Mountains in the 1940s and first observed in the Rincons in 1959 (Davis and Sidner 1992), are now “native” and that all cottontails found above 2000 m are eastern cottontails (*Sylvilagus floridanus*), although a specimen is needed to confirm identification of this species.

Results

During May 2011 to March 2012, we sampled for approximately 7,837 camera nights (tables 1 and 2). The cameras functioned during most but not all camera-checks and so the number of actual operational camera nights is fewer and unknown. We sampled at 173 points: 47 in the low elevation strata, 47 low-medium, 40 in medium-high, and 39 in high in elevation. We obtained 1,943 photos containing medium-to-large mammals that could be identified to species, as well as many photos of nocturnal rodents, birds, reptiles, humans, and other non-target species. We detected a total of 23 native species during the study period, including 17 in low elevation, 18 in low-medium, 12 in medium-high, and 10 in high elevation (table 1). We estimated the native species richness of the Rincon Mountains to be 24.8 species (SD = 1.2).

The most commonly photographed species were desert cottontail (*Sylvilagus audubonii*), white-tailed deer (*Odocoileus virginianus*), and antelope jackrabbit (*Lepus alleni*) (fig. 3). Five species were photographed less than 6 times during the study period: mule deer (*Odocoileus hemionus*), Abert’s squirrel (*Sciurus aberti*), round-tailed ground squirrel (*Spermophilus tereticaudus*), Western spotted skunk (*Spilogale gracilis*), and American badger (*Taxidea taxus*). We did not detect any species that had not been previously documented for the Rincon Mountains, although we did photograph one species (American badger) that had not been previously documented by camera-traps. We failed to detect two species (Virginia opossum [*Didelphis virginiana*] and Northern raccoon [*Procyon lotor*] that were detected in the Rincon Mountains by non-randomly placed cameras during the same study period (Saguaro National Park, unpublished data). We also failed to detect one species (cliff chipmunk [*Tamias*

dorsalis]) that was confirmed by numerous reliable observations and one species (Arizona gray squirrel [*Sciurus arizonae*]) that was detected during the inventories in 1999–2005. We did not detect five species, including grizzly bear, jaguar, gray wolf, bighorn sheep, and North American porcupine (*Erethizon dorsalis*) that were confirmed either by specimen or very reliable historical record to be present in the Rincon Mountains at some time during the period between 1900 and 1999 (Swann 2011). We did not detect free-ranging, non-native domestic dogs (*Canis familiaris*), domestic cat (*Felis catus*), or cattle (*Bos taurus*), which are known to occur in the Rincon Mountains at times (Swann 2011) but probably not in established populations.

Discussion

Our study demonstrates some advantages and limitations of using infrared-triggered camera-traps to inventory and monitor medium and large mammals, where we define the term *inventory* as the development of a species list for an area and *monitoring* as a method to determine changes in a measure such as species richness over time. Camera-traps have some major advantages over traditional inventory and monitoring methods for larger mammals. These methods include kill-trapping and hunting which provide reliable identification but raise ethical issues and have the potential to impact populations; live-trapping, which provides reliable identification but is expensive and has safety issues for animals and researchers; visual identification of scat and sign, which is non-invasive but the results cannot be verified to prevent false identification; genetic identification of scat and hair, which is growing in its potential as a non-invasive, reliable method, but can be expensive and incomplete due to DNA degradation of scat in a field environment (Piggot and Taylor 2003); observation records, which are inexpensive to gather but produce results that cannot be independently verified (Giordano and others 2011); and collection of voucher specimens of roadkills and other dead animals, as well as collection of vouchers photographs by citizen scientists, which are inexpensive and verifiable but require a very long effort in time due to species avoidance of humans and raise complicated study design issues.

One advantage of camera-traps for inventory and monitoring is that the results can be independently verified. The results of some classic papers in conservation biology (Newmark 1995) have been questioned due to their use of unverified observational records (Parks and Harcourt 2002). In addition, camera-traps can be easily deployed in a repeatable study design. Our study demonstrates that cameras placed at random locations, as opposed to only at water holes, game trails, and other locations known to attract certain species, will detect large numbers of species present in an area even if no bait or other attractants are used. Baiting camera-traps for a study of multiple

Table 1—Summary data on effort and results of camera trap study in the Rincon Mountains, May 2011–March 2012.

Strata	Elevation range	Area of sampling unit	No. of camera points	No. of camera nights	No. of photos	No. of species	Species richness estimate
	(m)	(ha)					(SD)
1	814-914	5,066	47	2,015	1,216	17	19.9 (1.9)
2	914-1,524	27,714	47	1,876	302	18	18.9 (0.9)
3	1,524-2,134	27,040	40	1,900	218	12	14.7 (1.9)
4	2,134-2,641	7,469	39	2,046	207	10	11.8 (1.2)
Total		67,289	173	7,837	1,943	57	24.8 (1.2)

Table 2—Species of terrestrial mammals, excluding nocturnal rodents and pocket gophers, confirmed for Rincon Mountain District, Saguaro National Park. Sources are (1) photo during this study, (2) photos or specimens collected during 1999-2010 (Swann and Powell 2006), and (3) photos, specimens, or very reliable record from 1900-1999 (Swann 2011), but no recent records. Source for names: Wilson and Ruff (2000).

Species	Photo this study	Confirmed 1999-2010	Confirmed 1900-1999 only
Marsupials			
Virginia opossum (<i>Didelphis virginiana</i>)	- ^a	X	
Rabbits and Hares			
Antelope jackrabbit (<i>Lepus alleni</i>)	X	X	
Black-tailed jackrabbit (<i>Lepus californicus</i>)	X	X	
Desert cottontail (<i>Sylvilagus audubonii</i>)	X	X	
Eastern cottontail (<i>Sylvilagus floridanus</i>)	X ^b	X	
Rodents – Squirrels and Porcupines			
Abert's squirrel (<i>Sciurus aberti</i>) ^c	X	X	
Arizona gray squirrel (<i>Sciurus arizonensis</i>)		X	
Harris's antelope squirrel (<i>Ammospermophilus harrisi</i>)	X	X	
Round-tailed ground squirrel (<i>Spermophilus tereticaudus</i>)	X	X	
Rock squirrel (<i>Spermophilus variegates</i>)	X	X	
Cliff chipmunk (<i>Tamias dorsalis</i>)		X	
North American porcupine (<i>Erethizon dorsatum</i>)			X
Carnivores			
Ringtail (<i>Bassariscus astutus</i>)	X	X	
Feral dog (<i>Canis familiaris</i>) ^c	- ^a	X	
Coyote (<i>Canis latrans</i>)	X	X	
Common hog-nosed skunk (<i>Conepatus mesoleucus</i>)	X	X	
Gray wolf (<i>Canis lupus</i>)			X
Mountain lion (<i>Puma concolor</i>)	X	X	
Feral cat (<i>Felis catus</i>) ^c		X	
Bobcat (<i>Lynx rufus</i>)	X	X	
Hooded skunk (<i>Mephitis macroura</i>)	X	X	
Striped skunk (<i>Mephitis mephitis</i>)	X	X	
White-nosed coati (<i>Nasua narica</i>)	X	X	
Jaguar (<i>Panthera onca</i>)			X
Northern raccoon (<i>Procyon lotor</i>)	- ^a	X	
Western spotted skunk (<i>Spilogale gracilis</i>)	X	X	
American badger (<i>Taxidea taxus</i>)	X	X	
Common gray fox (<i>Urocyon cinereoargenteus</i>)	X	X	
Black bear (<i>Ursus americanus</i>)	X	X	
Grizzly bear (<i>Ursus arctos</i>)			X
Hoofed mammals			
Domestic cattle (<i>Bos taurus</i>) ^c		X	
Mule deer (<i>Odocoileus hemionus</i>)	X	X	
White-tailed deer (<i>Odocoileus virginianus</i>)	X	X	
Bighorn sheep (<i>Ovis canadensis</i>)			X
Collared peccary (<i>Pecari tajacu</i>)	X	X	

^aRecent photographs exist, but not from cameras at random points during this study.

^bEastern cottontails are presumed based on appearance and habitat, but it is not possible to confirm this species based on sightings or photographs without a voucher specimen.

^cNon-native species.

species raises the potential for biasing results in studies of mammal communities (Kays and others 2011). We obtained a large number of photos of animals without using bait and without targeting water holes, game trails, or other macro-habitat features.

A major issue in inventories as opposed to monitoring (see below) that cannot be resolved by camera-traps is that of incomplete detect-

ability or the failure to detect species when they are indeed present. Camera-traps are like live-traps and other methods in that they vary in their ability to detect species, especially when they are set in a standard manner at random points. We expect that some individual animals may notice and avoid cameras, some may be attracted to them, and some may not be detected by cameras due to their small size or

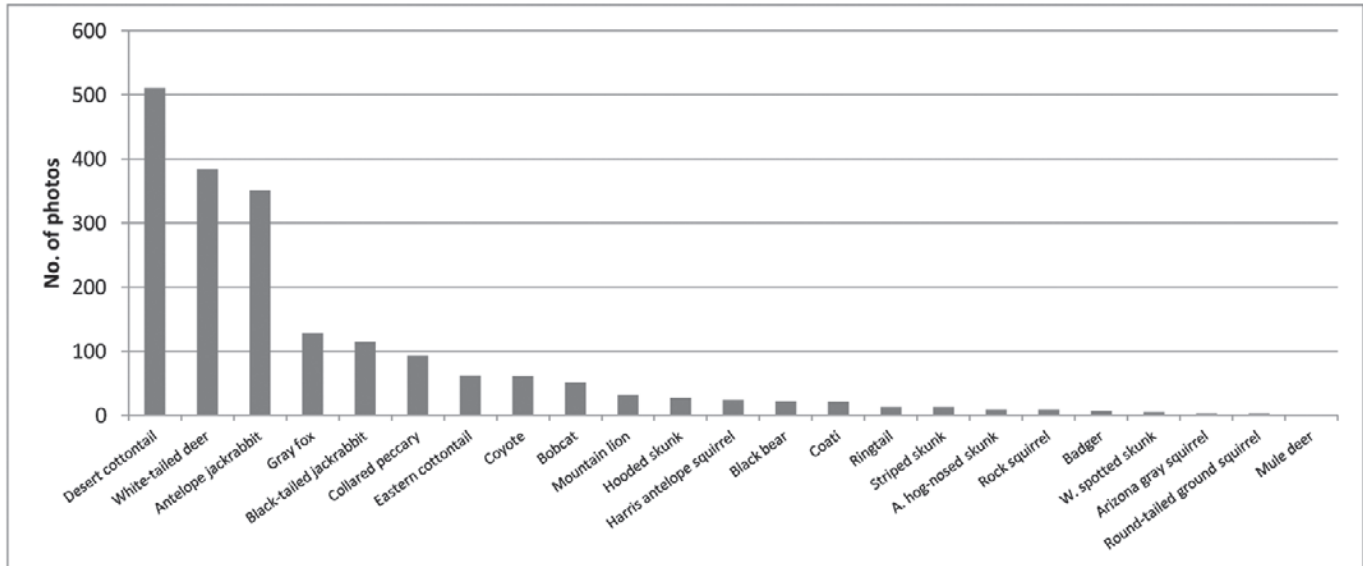


Figure 3—Number of photos for each of the 23 native terrestrial mammal species (excluding nocturnal rodents and pocket gophers) photographed by camera traps in the Rincon Mountains during May 2011-March 2012.

quick movements. Despite a large effort, we did not detect several species that were photographed in the Rincon Mountains during the past decade (Swann 2011). We suspect that these species were present in the park for at least part of our study but went undetected due to their relative rarity, small size (cliff chipmunk), or specific habitat needs (e.g., Arizona gray squirrels who occur mostly in trees). We believe we would detect more species with increased sampling effort, although this effort may need to be very large. Therefore, for a mammal inventory of an area to be as complete as possible, we recommend that some cameras be set in targeted habitats. For example, setting cameras at the base of oak trees to detect Arizona gray squirrels, a rare habitat specialist, may be the most efficient way to detect this species in the Rincon Mountains.

For monitoring, the problem of incomplete detectability is common to all wildlife monitoring studies and can be overcome through a design that quantifies the probability of detection and estimates the measure of interest. Species richness, particularly of native species, is often used to determine changes in biological diversity, and can be estimated from camera trap studies using a number of models and approaches (Tobler and others 2008; O'Brien and others 2011), including a fairly simple approach using program EstimateS, as we have done in this paper. Our estimated native species richness of 24.8 ± 1.2 for the Rincon Mountains seems to be reasonable, given that 27 native species have been detected by all methods since 1999.

As one of the most northern and western of the Sky Islands, the Rincon Mountains might be expected to have a reduced number of mammals of tropical origin compared to more southern and eastern ranges such as the Chiricahua Mountains, Huachuca Mountains, and others. Compared to other Sky Islands, the Rincon Mountains have fewer reptile and amphibian species, and lack at least seven montane species found even as close as the nearby Santa Rita Mountains (Swann and others 2005). Medium and large mammals should be able to move among Sky Islands more easily than reptiles and some other taxa, and indeed a number of recent genetic studies have shown that larger mammals such as bears can be closely related among nearby sky islands (Varas and others 2005). We photographed opossums at non-random sites, a more southern species that appears to be expanding its range to the

north (Babb and others 2004), but did not detect ocelots or jaguars. There are apparently no confirmed records of ocelots from the Rincons but at least four jaguars were confirmed (killed by hunters) in the Rincon Mountains during 1900-1932 (Swann 2011). Several other terrestrial mammals that occur in the area, such as kit fox (*Vulpes macrotis*), have never been documented in the Rincon Mountains.

At least five species that we did not detect are known to have occurred in the Rincon Mountains during the past century (Swann 2011). In addition to jaguar, these include grizzly bear (last record a hunter kill in the 1920s); Mexican gray wolf (last records from the 1950s); bighorn sheep (last records from the 1950s); and North American porcupine (last record a reliable observation in the 1990s). Of these five species, grizzly bear and Mexican gray wolf are extirpated from the region. Jaguars and bighorn sheep are probably extirpated from the Rincon Mountains, but both are wide-ranging species that could be expected to occur occasionally. Porcupines appear to be declining throughout Arizona, possibly due to the increase in predators, especially mountain lions (Brown and Babb 2009).

Management Implications

Despite the great interest in mammals of the Sky Islands, the need for regional monitoring and improvements in our ability to detect rare species such as jaguars, many Sky Islands still do not have basic inventories and the region does not have a current standardized monitoring plan. Camera-traps are an emerging technology that may provide opportunities to address these issues. Comprehensive monitoring need not be an expensive investment, due to volunteer efforts by groups such as the Sky Island Alliance (SIA), and because monitoring intervals can be widely separated in time, but it would require a coordinated effort. A great advantage of using camera-traps over other monitoring methods is that they provide interesting photos and videos that not only possess important scientific value but can be enjoyed by the public through a wide variety of social media. Photos and videos from our study have been made available through Facebook and a number of websites including Flickr, National Geographic Society, and Friends of Saguaro National Park.

The project described in this paper was initiated and inspired by the 2011 BioBlitz, a major biodiversity event that took place at Saguaro National Park in October 2011 and was supported by the National Geographic Society, Friends of Saguaro National Park, and many other organizations. The BioBlitz matched nearly 200 scientists and experienced naturalists in the field with more than 2,500 Tucson school children and adult volunteers to sample the park's biodiversity. As part of the BioBlitz, we developed a program with SIA, the National Park Foundation, AmeriSchools College Preparatory Academy, and others that enabled middle and high-school students to track wildlife with expert SIA trackers and download wildlife photos from camera traps that had been previously set by high school volunteers. The program provided a hands-on wildlife experience, with students succeeding in capturing a number of species on film including mountain lions (fig. 4) and coatis. The growing use of camera-traps by both biologists and educators has great potential to engage the public directly in the conservation of Sky Island mammals while also providing data useful for long-term conservation.

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Figure 4—Mountain lion (*Felis concolor*) photographed by a camera trap in the Rincon Mountains for the BioBlitz educational program in October, 2011.

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Habitat Type and Permanence Determine Local Aquatic Invertebrate Community Structure in the Madrean Sky Islands

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Abstract—Aquatic environments in the Madrean Sky Islands (MSI) consist of a matrix of perennial and intermittent stream segments, seasonal ponds, and human-built cattle trough habitats that support a diverse suite of aquatic macroinvertebrates. Although environmental conditions and aquatic communities are generally distinct in lotic and lentic habitats, MSI streams are characterized by isolated perennial pools for much of the year, and thus seasonally occur as lentic environments. In this study, we compared habitat characteristics and Coleoptera and Hemiptera assemblages of stream pools with those of true lentic habitats (seasonal ponds and cattle troughs) across the MSI. We identified 150 species across the 38 sites, and despite superficial similarities in habitat characteristics, seasonal ponds and stream pools in the MSI support distinct aquatic insect communities. Stream-exclusive species included many long-lived species with poor dispersal abilities, while pond-exclusive species tended to have rapid development times and strong dispersal abilities. We suggest that, in addition to perennial streams, seasonal aquatic habitats should also be a focus of conservation planning in the MSI.

Introduction

Abiotic factors can be highly influential in determining local aquatic invertebrate community structure, including presence or absence of flowing water (lotic vs. lentic) and hydroperiod (how long water lasts in a given habitat). Lotic and lentic environments generally support distinct aquatic insect communities (Huryn and others 2008). The physical hydraulics of flow, oxygen availability, substrate, and temperature are among the primary physical drivers of this community distinctness between lotic and lentic habitats (Vannote and Sweeney 1980; Resh and others 2008). Additionally, seasonal habitat drying can act as a strong filter on aquatic insect communities in both streams and ponds (Williams 2005). Seasonal streams and ponds (habitats that dry for extended periods of time each year) often contain species with life-history adaptations to drought (Wiggins and others 1980).

The Madrean Sky Island region (MSI) in the southwestern United States and northwestern Mexico contains a diversity of lotic and lentic habitats, including streams with perennial and intermittent surface water, seasonal ponds, and human-built cattle troughs. Perennial

streams are found in the higher elevations (1200-2200 m) of most MSI mountain ranges. While wet winters and monsoon rains can result in high-flow periods where stream pools are scoured and connected to one another, many MSI streams have low to zero flow for much of the year, and the remaining isolated perennial pool habitats approximate lentic environments. Seasonal ponds form in adjacent valley bottoms; these ponds fill after summer monsoon rains or prolonged winter storms and usually contain water for fewer than 4 months. Cattle troughs also provide small lentic habitats, which often contain water year-round. All three of these environments provide lentic habitat, but whether or not they were utilized by the same taxa was previously unknown.

In this study, we surveyed stream pool, seasonal pond, and cattle trough aquatic insect assemblages across the MSI. We focused our analyses on beetles (Coleoptera) and true bugs (Hemiptera) because species-level identification is possible and they comprise over 80% of aquatic insect individuals in MSI stream pools during the dominant low-flow period (Bogan and Lytle 2007). Our objectives were to document the distribution of these taxa across the MSI and to examine assemblage differences among stream pool, seasonal pond, and cattle trough habitats. While MSI stream pools approximate lentic environments for much of the year, we hypothesized that stream pools, seasonal ponds, and cattle troughs would contain distinct beetle and true bug assemblages due to environmental differences (e.g. hydroperiod, water temperature) among these habitat types.

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Methods

Habitat Types

Perennial stream pools occur as small, fragmented habitats within MSI ranges (generally between 1200 and 2200 m), and contain water year-round. Seasonal ponds (occurring below 1200 m) that we surveyed in 2004 were dry in April and June, wetted in August, and dry again in November. Thus, these ponds contained water for no more than 4 consecutive months in 2004. Cattle troughs were found in the lower reaches of canyons (usually below 1500 m) and in valleys below 1200 m. These were small (1 to 10 m²) concrete and metal tanks that were fed by spring or well water. Cattle troughs generally contain water year-round, but can dry occasionally if the pumps, hoses, or pipes that feed them break. The history of individual troughs (e.g. when they were constructed) was not available for this study. None of the streams, seasonal ponds, or cattle troughs surveyed contained exotic vertebrate predators (e.g. large-mouthed bass, bullfrogs) when they were surveyed.

Collection Methods

Aquatic beetle and true bug assemblages were sampled from pools in 25 streams, from 7 seasonal ponds, and from 5 cattle troughs between May and July 2004. Streams were the focus of a separate study (Bogan 2005), which is why more streams were surveyed than ponds or troughs. Stream pools were sampled by vigorously sweeping a D-net (1 mm mesh) above all pool substrata and on the surface of the water for 10 s m⁻² of pool area, an effort that detected approximately 95% of beetle and true bug taxa in a given pool (see Bogan and Lytle 2007, 2011). Ponds, and occasionally troughs, were too large to effectively sample the entire habitat as was done for stream pools, so we focused our efforts on near-shore habitats. At each pond and trough sampling site, a 1-mm mesh D-net was used to vigorously sweep substrate and vegetation from the shore to 2 m offshore along the entire habitat perimeter. All collected insects were placed in 95% ethanol, and later identified at Oregon State University. At each sample site, temperature, pH, and conductivity were recorded at a depth of 10 cm using hand-held meters. Since sampling did not always occur at the same time of day, instantaneous water temperature values may

Table 1—Location of study sites in the Madrean Sky Islands region (SON = Sonora, Mexico; AZ = Arizona; NM = New Mexico).

Habitat type	Site	State	Latitude	Longitude
Stream pools	Agua Caliente- Aconchi	SON	29.846	110.2849
	Agua Caliente- Cajon	SON	31.2824	108.9963
	Cañon Alacrán	SON	28.01	111.2
	Ash Creek	AZ	32.50679	110.23639
	Bear Canyon	AZ	31.41056	110.2826
	Cajon Bonito	SON	31.27803	109.00212
	Chulo Canyon	AZ	31.48545	109.98251
	Dixie Canyon	AZ	31.49549	109.89718
	East Turkey Creek	AZ	31.91743	109.23194
	Florida Canyon	AZ	31.75657	110.84362
	French Joe Canyon	AZ	31.81758	110.40917
	Gardner Canyon	AZ	31.70217	110.80051
	Leslie Creek	AZ	31.58916	109.50729
	Madera Canyon	AZ	31.72416	110.88071
	Sierra Mazatán	SON	29.09106	110.22091
	Miller Canyon	AZ	31.40691	110.28742
	Cañon Nacapule	SON	28.00898	111.09712
	Ramsey Canyon	AZ	31.4442	110.3171
	Rattlesnake Creek	AZ	32.69534	110.34395
	Rucker Canyon	AZ	31.75669	109.36433
Seasonal ponds	Simpson Spring	AZ	31.78932	110.47029
	Sycamore Creek	AZ	31.41914	111.19361
	Vallecitos- La Madera	SON	29.92156	109.51361
	West Stronghold Canyon	AZ	31.93385	109.99599
	West Turkey Creek	AZ	31.86102	109.33618
	Boulder Pond	AZ	31.76126	110.4856
	East Willow Pond	AZ	31.81503	109.05965
Cattle troughs	Exit 292 Pond	AZ	31.97767	110.50866
	Halfmoon Pond	AZ	31.91235	109.97793
	Rock Pond	AZ	31.94488	109.11757
	Stuck Pond	NM	31.86468	109.03671
	The Thing Pond	AZ	32.08254	110.05257
	Bear Spring Tank	AZ	31.77523	110.4616
	Cottonwood Tanks	AZ	31.48941	109.07038
Guindani Tank	AZ	31.84151	110.36936	
Kartchner Tank	AZ	31.8835	110.35767	
Rock Tank	AZ	31.93941	109.11703	

not exhibit reliable differences between sites. To explore diurnal water temperature fluctuations, we deployed HOBO remote temperature probes (Onset Computer Corporation, Pocasset, MA) at 10 cm water depth in two ponds (East Willow and "Stuck"; table 1) and pools in two streams (one pool each in N. Fk. Cave Creek and French Joe Canyon; table 1). HOBO probes in the streams were deployed from May 2004 through June 2005, but the seasonal pond sites began to dry soon after the probes were deployed, so data are only available from 29 July-2 August 2004. Finally, we visually estimated percentages of substrate types (bedrock, cobble, gravel, sand, and fines) at each site. All insect collections and visual estimations were made by the same individual (MTB) to minimize data collector error.

Statistical Methods

Because sample sizes and variances were unequal, we used non-parametric Mann-Whitney tests to examine differences in temperature, conductivity, and pH between stream and pond sites. All tests were performed in SYSTAT v.11 (Systat Software Inc., San Jose, California). Aquatic insect assemblage variation among sites was visualized using non-metric multidimensional scaling (NMS) on Sorensen distance matrices in PC-ORD v5.0 (MjM Software, Glenden Beach, Oregon). Because pond aquatic invertebrate sampling methods were designed to maximize species detection, rather than quantifying relative abundances, all assemblage matrices were presence-absence transformed prior to statistical analyses. We used Pearson's r correlations to examine relationships between species presence, environmental factors, and axis scores. To test distinctness of stream and pond assemblages, we used Multi-Response Permutation Procedure (MRPP) tests.

Results

Pond temperatures during sampling visits (mean \pm 1 SD: 23.5 $^{\circ}$ C \pm 5.6) were significantly higher than stream pool temperatures (mean \pm 1 SD: 20.1 $^{\circ}$ C \pm 3.1; $U = 225.5$, $p = 0.03$), but conductivity and pH did not differ significantly between streams and ponds ($p = 0.47$ and 0.46, respectively). The HOBO temperature probes deployed from 29 July - 2 August 2004 indicated that, in addition to overall higher temperatures in ponds over those 5 days, diurnal temperature fluctuation was much higher in ponds than in stream pools (fig. 1). Mean pond temperature over those 5 days was 25.6 \pm 5.1 $^{\circ}$ C, while mean stream pool temperature was 18.3 \pm 2.3 $^{\circ}$ C. Pond substrate was predominately fine silt (mean \pm 1SD: 80% \pm 16), while stream pool substrate was variable (means \pm 1SD: 38% \pm 26 bedrock, 20% \pm 22 fine, 16% \pm 15 gravel, 16% \pm 16 cobble, 10% \pm 13 sand).

One-hundred and fifty species of Coleoptera and Hemiptera were identified from the 25 stream, 7 seasonal pond, and 5 cattle trough sites. Sixty-five species (43% of all species) were exclusive to stream pools, while 15 species (10% of all species) were exclusive to seasonal ponds. Forty-six species (31% of all species) were habitat generalists, encountered in both pond and stream habitats (see tables 2 and 3). No species were unique to cattle troughs. The remaining 24 species (16% of all species) were only encountered at one site so we could not confidently evaluate their habitat affinity.

The NMS ordination converged on a stable, 2-D solution (final stress = 18.7%, final instability = 0.003; $p = 0.02$; fig. 2). The ordination explained 81% of the variance in the original species matrix (axis 1: $r^2 = 0.37$; axis 2: $r^2 = 0.44$). Axis 1 was influenced by *Aquarius remigis* ($r = -0.55$), *Pelocoris* ($r = 0.50$), and *Hydrophilus insularis* ($r = 0.79$) among other species while axis 2 was influenced by *Notonecta lobata* ($r = -0.75$), *Thermonectus marmoratus* ($r = -0.69$),

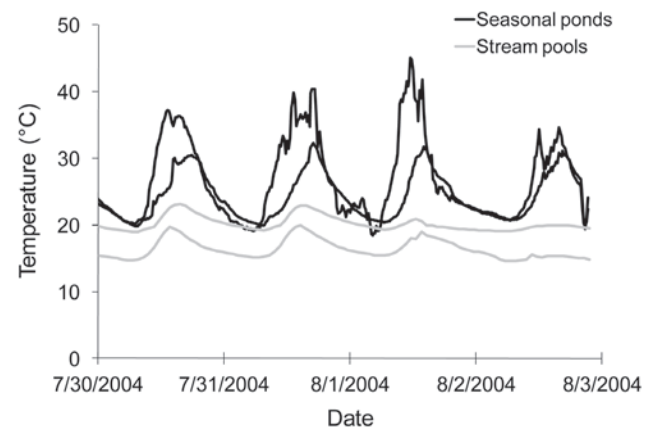


Figure 1—Diurnal water temperature fluctuations recorded at 15-minute intervals in two seasonal ponds (black lines) and two stream pools (grey lines) from 00:00h 30 July 2004 to 21:00h 2 August 2005. Each cross-hatch on the x-axis represents the beginning of that day (00:00h). The lower stream pool line is from North Fork Cave Creek and the upper is from French Joe Canyon. The lower seasonal pond line is from East Willow pond and the upper line is from "Stuck" pond (see table 1).

Desmopachria portmanni ($r = -0.65$), *Gyrinus plicifer* ($r = -0.64$), and *Corisella edulis* ($r = 0.71$), among others. Axis 2 values were positively associated with fine substrates ($r = 0.75$) and negatively associated with bedrock substrates ($r = -0.53$). Latitude was negatively associated with axis 1 ($r = -0.45$) and temperature was positively associated with axis 2 values ($r = 0.42$); however, both of these factors appear to be associated with assemblage gradients described in part by both axes (i.e., the vectors are diagonal to axes 1 and 2; fig. 2).

Most stream pool sites formed a tightly clustered group in the NMS graph (fig. 2). Stream pools located on the extreme southwestern margin of the MSI (Mazatán, Nacapule and Alacrán; table 1) had higher axis 1 scores than other streams pools, but were within the range of axis 2 scores for all other streams. Seasonal pond assemblages varied widely, while cattle trough assemblages showed less variability and were closer in composition to stream pool assemblages. MRPP analyses confirmed the distinctness of stream pool, seasonal pond, and cattle trough assemblages ($A = 0.29$, $p < 0.0001$).

Discussion

Despite superficial similarities in habitat characteristics, stream pools and seasonal ponds in the MSI support distinct aquatic beetle and bug assemblages. Of the 150 species identified in this study, 80 species were exclusive to either stream pools or seasonal ponds. Sixty-five of these species were only found in the perennial stream pools, while the remaining 15 were exclusively found in the environmentally variable seasonal ponds (tables 2 and 3). The relatively low number of pond exclusive species may be due to harsh environmental conditions in ponds, but could also be due to the low number of ponds sampled ($n = 7$) when compared with streams ($n = 25$). Fairy shrimp and other non-insect invertebrates are often specialists in seasonal ponds (King and others 1996), so a broader taxonomic consideration of our study ponds and pools would likely only increase the community distinction among these three habitat types.

Temperature has been identified as a major factor in aquatic insect species distributions in numerous studies (e.g. Hawkins and

Table 2— Coleoptera species identified from Madrean Sky Island region ponds and stream pools with their habitat affinities. Only common taxa (occurrences in >10% of sites) are listed in order of percentage of sites at which they were found (%). Generalist species were found in at least two of the three habitat types sampled.

Stream pool exclusive	%	Seasonal pond exclusive	%	Generalist species	%
<i>Thermonectus marmoratus</i>	81	<i>Berosus styliifer</i>	57	<i>Laccophilus fasciatus</i>	80
<i>Gyrinus plicifer</i>	73	<i>Eretes sticticus</i>	29	<i>Berosus salvini</i>	66
<i>Dineutus sublineatus</i>	69	<i>Berosus cf. infuscatus</i>	29	<i>Rhantus gutticollis gutticollis</i>	61
<i>Rhantus atricolor</i>	62	<i>Berosus cf. miles</i>	29	<i>Stictotarsus striatellus</i>	51
<i>Sanfilippodytes</i>	62	<i>Neoclypeodytes sp.</i>	14	<i>Tropisternus ellipticus</i>	51
<i>Stictotarsus corvinus</i>	62	<i>Berosus peregrinus</i>	14	<i>Stictotarsus aequinoctialis</i>	49
<i>Berosus rugulosus</i>	58			<i>Tropisternus lateralis</i>	49
<i>Rhantus gutticollis mexicanus</i>	38			<i>Desmopachria portmanni</i>	46
<i>Postelichus immisi</i>	35			<i>Thermonectus nigrofasciatus</i>	44
<i>Helichus triangularis</i>	31			<i>Peltodytes dispersus</i>	41
<i>Hydraena sp.</i>	31			<i>Berosus moerens</i>	41
<i>Hydrochus sp.</i>	31			<i>Hygrotus sp.</i>	39
<i>Stictotarsus roffi</i>	27			<i>Laccophilus horni</i>	39
<i>Helichus suturalis</i>	23			<i>Liodessus obscurellus</i>	37
<i>Neoclypeodytes fryii</i>	23			<i>Agabus sp.</i>	34
<i>Laccobius sp.</i>	23			<i>Desmopachria mexicana</i>	34
<i>Dytiscus habilis</i>	19			<i>Laccophilus maculosus</i>	29
<i>Anacaena limbata</i>	19			<i>Enochrus sp.</i>	27
<i>Laccophilus oscillator</i>	15			<i>Hydrophilus insularis</i>	22
<i>Elmidae sp.</i>	15			<i>Berosus punctatissimus</i>	17
<i>Liodessus sp.</i>	12			<i>Laccophilus mexicanus</i>	15
				<i>Neoclypeodytes cinctellus</i>	15
				<i>Helophorus sp.</i>	15
				<i>Laccophilus pictus</i>	12

Table 3—Hemiptera species identified from Madrean Sky Island region ponds and stream pools with their habitat affinities. Only common taxa (occurrences in >10% of habitats) are listed in order of percentage of sites at which they were found (%). Generalist species were found in at least two of the three habitat types sampled.

Stream pool exclusive	%	Seasonal pond exclusive	%	Generalist species	%
<i>Abedus herberti</i>	77	<i>Corisella edulis</i>	100	<i>Microvelia sp.</i>	76
<i>Ambrysus woodburyi</i>	35	<i>Gerris sp.</i>	43	<i>Graptocorixa abdominalis</i>	71
<i>Trepobates becki</i>	31	<i>Notonecta unifasciata</i>	43	<i>Notonecta lobata</i>	63
<i>Pelocoris sp.</i>	31	<i>Belostoma flumineum</i>	29	<i>Ranatra quadridentata</i>	59
<i>Notonecta kirbyi</i>	23	<i>Corisella tarsalis</i>	14	<i>Aquarius remigis</i>	54
<i>Platyvelia beameri</i>	23	<i>Corisella sp.</i>	14	<i>Buenoa arizonis</i>	44
<i>Rhagovelia varipes</i>	23	<i>Ramphocorixa acuminata</i>	14	<i>Graptocorixa serrulata</i>	39
<i>Hydrometra sp.</i>	19	<i>Notonecta undulata</i>	14	<i>Lethocerus medius</i>	34
<i>Curicta pronotata</i>	19	<i>Salda sp.</i>	14	<i>Buenoa arida</i>	32
<i>Graptocorixa gerhardi</i>	12			<i>Buenoa scimitra</i>	29
<i>Neocorixa snowi</i>	12			<i>Morphocorixa lundbladi</i>	20
<i>Gelastocoris sp.</i>	12			<i>Notonecta hoffmani</i>	17

others 1997). Indeed, we found that ponds had significantly higher temperatures than stream pools and also that increased temperature was associated with the shift from stream pool to seasonal pond assemblage types. Additionally, diurnal variability in temperature appears to be much higher in seasonal ponds (fig. 2), though we did not measure this factor at all sites. Temperature variability may be a more important factor than mean temperature when examining environmental drivers of observed aquatic community differences (Palmer and others 1997). High and variable temperatures can impact aquatic insect respiration and survival of early instars by changing oxygen levels and water density (Williams 2005). As seasonal ponds only occurred below 1200 m and stream pools only occurred above 1200 m, elevation is clearly a confounding factor in this study. Tem-

perature and dissolved oxygen often co-vary with elevation, and we are unable to disentangle the effects of water quality and elevation in this study. We also did not measure nutrient levels, which may be higher in seasonal ponds visited by livestock, and recommend that such measurements be included in future studies.

Local physical habitat characteristics (e.g. substrate, channel morphology) can also strongly influence local aquatic invertebrate assemblages within a given biogeographic region. Sanderson and others (2005) determined that a gradient from silt- to boulder-dominated substrates was the most important physical factor determining stream invertebrate abundances in a northern England river system. Similarly, we identified a gradient in local beetle and true bug assemblages that was strongly associated with a shift from bedrock-dominated to

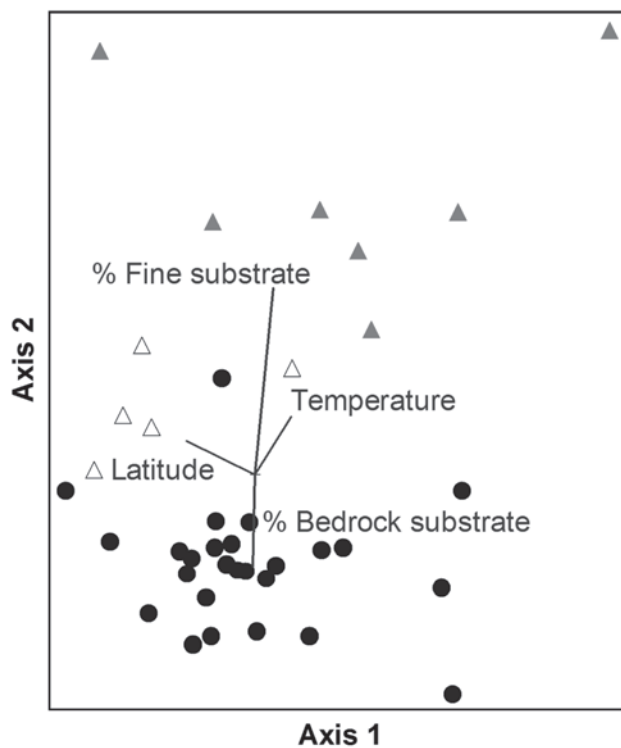


Figure 2—NMS ordination of the beetle and true bug assemblages from 26 stream pool sites (black circles), 7 seasonal valley pond sites (open triangle) and 5 constructed cattle tank sites (grey triangles). Environmental factors with Pearson's correlations greater than 0.4 with either axis are illustrated as vectors. The length of each factor's vector is proportional to that factor's correlation values with the two axes.

finer-dominated substrate across all our study sites and habitat types (NMS axis 2; fig. 2).

Williams (2005) noted that a short hydroperiod may be the most constraining environmental factor for determining the distribution of aquatic organisms. Although we did not measure exact hydroperiod at our study sites, we know that ponds held water for less than 4 months during 2004. The habitat affinities of several species in our study, however, may provide insight into how short hydroperiods (as found in seasonal ponds) could act to constrain MSI beetle and true bug assemblages. Several of the exclusively stream pool species are either flightless (e.g. *Abedus herberti*; Lytle 2000) or have weak dispersal abilities (e.g. *Rhantus atricolor*; R.L. Smith, personal communication), so it is intuitive that these species would be excluded from temporary habitats. Indeed, Zimmerman and Smith (1975) noted that *R. atricolor* collections are almost exclusively from perennial mountain streams. In contrast, many pond exclusive species are capable of far and frequent dispersal (e.g. *Corisella edulis*; Hungerford 1948) and may benefit from reduced competition and predation in harsh seasonal environments (Wellborn and others 1996). The pond exclusive dytiscid beetle *Eretes sticticus* appears to be especially well adapted to seasonal habitats. It has an extremely rapid larval development time (15 days; Kingsley 1985) and has been collected almost exclusively from temporary desert ponds (Larson and others 2000).

Beetle and true bug assemblages in cattle troughs were intermediate between those from stream pools and seasonal ponds and were more

similar to one another than seasonal pond assemblages (fig. 2). Aquatic insects must colonize these habitats after the troughs are constructed, creating a strong dispersal filter that could lead to more self-similar local assemblages. Since cattle troughs are filled by spring or well water, they generally contain water year-round. This longer hydroperiod may favor a distinct group of species with longer development times but tolerant of occasional dry periods (see Williams 2005) when a pipe breaks or the trough's source fails. Despite the apparent preference for human-constructed habitats by a number of dytiscid beetle species (Larson and others 2000) we did not find any species exclusive to cattle troughs.

Though widely distributed across a large geographic area (~30,000 km²), most stream pool assemblages were more similar to one another than were seasonal pond assemblages (fig. 2). Important environmental factors, such as relatively stable temperatures (fig. 1) and reliable perennial water, may allow longer-lived predators with weak dispersal abilities (e.g. top predator *Abedus herberti*: flightless, lifespan up to 3 years; Lytle 2000; Lytle and Bogan unpublished data) to persist in perennial stream pools but not in seasonal ponds. These predators, among other species ill-suited to seasonal pond conditions but highly competitive in perennial habitats, may contribute to the uniformity of stream pool assemblages by exerting a strong biotic influence on local communities (Wellborn and others 1996).

Much of the variability among stream pool sites was represented by axis 1 in the ordination, which was associated with latitude. Indeed, there appears to be a latitudinal assemblage shift, with some widespread Nearctic species (e.g. *Aquarius remigis* and *Rhantus gutticollis*) being characteristic of northern sites while taxa with Neotropical centers of distribution were characteristic of southern sites (e.g. *Pelocoris*, *Hydrophilus insularis*). The MSI are often described as a meeting place for Nearctic and Neotropical species, so it is not surprising that we detected a north-south gradient in assemblages while looking over a large geographic range (28°-32° latitude). We did not sample enough seasonal ponds in the southern part of the MSI (i.e. south of 31° latitude) to assess latitudinal gradients in pond assemblages.

While the results from this current study suggest that hydroperiod is an influential factor in determining lentic beetle and true bug assemblages across the MSI, hydroperiod may be even more important in lotic systems. In a recent study, we compared lotic aquatic invertebrate community structure in a network of perennial and intermittent stream reaches in the Huachuca Mountains (Bogan and others, in review). We found that intermittent reaches were species-poor when compared to perennial reaches, but that these species-poor communities were composed mostly of unique species with adaptations to life in temporary water and were not found in perennial reaches. The short flow duration of intermittent reaches (<4 months, often dry for 1 or more years at a time) strongly favors species with rapid development times and dormant egg or larval stages, such as winter stoneflies, blackflies, and non-biting midges. Thus, despite being species-poor relative to neighboring perennial reaches, intermittent stream reaches are important contributors to regional species richness.

We hope that the results of these studies will help inform aquatic conservation planning in the MSI region. Temporary waters and small perennial streams are often overlooked during conservation planning, while focus is placed on larger streams or perennial lakes. We identified a number of aquatic species in the MSI, however, that appear to prefer or be restricted to seasonal habitats. Many geographically restricted, endemic invertebrate species are found in seasonal ponds in other parts of the southwestern United States (e.g. King and others 1996). With sufficient taxonomic studies, new invertebrate species endemic to MSI intermittent streams and seasonal ponds would likely be described. Additionally, numerous other species seem to require

the stable perennial conditions associated with some streams. These species are increasingly threatened by drying climate and contracting or vanishing perennial stream habitat across the MSI. We are already witnessing stream-scale extirpations of important taxa (e.g. the top predator *Abedus herberti*) due to unprecedented drying of perennial habitats and increasing isolation of remaining perennial habitats (Bogan and Lytle 2011). In order to preserve local endemic species and regional aquatic diversity, aquatic conservation planning in the MSI should include a wide range of habitat types, from perennial to ephemeral and from lotic to lentic.

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Gila Topminnow Interactions With Western Mosquitofish: An Update

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Abstract—Western mosquitofish *Gambusia affinis* has major impacts on Gila topminnow *Poeciliopsis occidentalis*. Thirteen years have passed since information on negative impacts has been published. I will list and discuss additional examples where mosquitofish have impacted topminnow. In addition, it appears that long-term drought has a synergistic and negative effect on this relationship. Since the last publications detailing the loss of Gila topminnow populations to mosquitofish, two natural topminnow populations have been lost in the Santa Cruz River basin: Redrock Canyon and Sharp Spring. Drought and climate change likely exacerbated the impacts of mosquitofish on these two populations, speeding the decline and disappearance of topminnow from both. Dynamic conservation actions are required to conserve and recover the Gila topminnow.

Introduction

It has long been known and thoroughly documented that *Gambusia affinis* western mosquitofish (mosquitofish) has major deleterious effects on individual *Poeciliopsis occidentalis* Gila topminnow (topminnow) and their populations. It has been 13 years since information on these negative impacts has been updated. In this paper I will list and discuss additional examples where mosquitofish have impacted topminnow. I will also summarize the apparent mechanisms of how mosquitofish extirpate topminnow, and what the future of topminnow conservation might require.

The last peer-reviewed paper on topminnow-mosquitofish interaction was by W. L. Minckley (1999), and the last publication of any sort discussing this was by Voeltz and Bettaso (2003). Further information can be found in Minckley and others (1977, 1991) and Meffe and others (1983). These publications and others (Meffe and others 1982; Miller 1961) have made it abundantly clear that mosquitofish negatively impact topminnow, and documented the likely mechanisms responsible (Meffe 1984, 1985; Schoenherr 1974). However, a brief review of the mechanisms by which mosquitofish impact multiple species, and topminnow populations in particular, are appropriate.

Mosquitofish was first collected in Arizona in the Phoenix area in 1926 (Miller and Lowe 1964), in habitats that also held topminnow and other native fishes. Subsequently, mosquitofish came to be distributed, most likely through purposeful release, not all legally, throughout Arizona (Meffe 1985; Minckley 1973). They have also been released worldwide (Courtenay and Meffe 1989; ISSG 2010), and have been called the most introduced species in the world (Welcome 1988).

In addition to impacts on Gila topminnow, mosquitofish have impacted other native fish in the western United States (Deacon and others 1964; Meffe 1985; Whitmore 1997) and the rest of the world (Arthington and Lloyd 1989; Glover 1989; Milton and Arthington 1983; Unmack and Brumley 1991). Mosquitofish have also been shown or suspected to prey on tadpoles (Goodsell and Kats 1999; Morgan and Buttemer 1997; Webb and Joss 1997), newts (Gamradt and Kats 1996), frogs (Rosen and others 1995), and aquatic insects (Carchini and others 2003; Englund 1999). Several studies have demonstrated that mosquitofish (Crandall and Bowser 1982; Dykova and others 1994; Lom and Dykova 1995; Moravec 1998) and related species (Perlmutter and Potter 1987) carry parasites and disease that can be transferred into aquatic systems where they are released. Lastly, once introduced, mosquitofish are also known to cause cascading changes in the function of aquatic systems (Bence 1988; Hoy and others 1972; Hurlbert and others 1972; McDowall 1990; Ortega-Mayagoita and others 2002). Mosquitofish have been widely distributed by state vector control agencies to control mosquitoes.

The predominant mechanisms of mosquitofish effect on topminnow are aggression and predation (Meffe and others 1983; Minckley and Deacon 1968; Schoenherr 1977). Mosquitofish often replace topminnow in a matter of months (Meffe and others 1983; Schoenherr 1974), but with exceptions where the two species coexisted for years (Minckley 1999). Possible means of coexistence have been shown to be the species' differential response to flooding (Galat and Robertson 1988; Meffe 1984), or theorized greater habitat size and complexity (Meffe 1985). Another potential mechanism for prolonged coexistence is that mosquitofish do not invade springheads with extreme water quality (Hubbs 1995), but are occupied by congeners (Hubbs 1957, 1971). Topminnow is tolerant of extreme springhead conditions (Marsh and Minckley 1990; Minckley 1973). The sites where mosquitofish have extirpated topminnow in a few months to a few years have all been small and simple habitats, generally reestablishment sites; in natural habitats replacement takes longer.

Minckley (1999) also mentioned an additional alternative based on work by Hubbs (1991, 1992, 1996) showing that some western mosquitofish do not cannibalize their young. Minckley theorized that certain stocks of mosquitofish could be less predatory, and that could

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be an explanation for coexistence of topminnow and mosquitofish. Minckley (1999) also offered an alternative hypothesis involving groundwater inflow. Groundwater inflow tends to be warmer than surrounding waters, and may provide thermal refuge during periods of prolonged freezing temperatures. However, topminnows have been observed swimming below surface ice. Most perennial waters that harbor or have harbored topminnow also are groundwater dependent. However, I believe reliable water is the reason topminnows persist at those sites, and not the thermal refuge provided there.

Results/Update

There are several additional topminnow sites with mosquitofish where topminnow in Arizona have been lost since Minckley's review (1999). Table 1 shows these sites, as well as updates the status of the natural populations. The draft revised Gila topminnow recovery plan (Weedman 1999:58) defines a natural population as "a population which existed prior to fish transplants by humans, which exists today in its historic location free of known mixing with other populations by humans (Simons 1987)." While only a few sites have been recently lost to mosquitofish, any loss of populations of an endangered species is disconcerting, especially natural populations, which are crucial for species survival (Weedman 1999).

There have been two natural populations lost since 1999. Sharp Spring, a tributary headwater spring to the upper Santa Cruz River, was where Meffe (1984) conducted field studies demonstrating that Gila topminnow withstood floods better than mosquitofish. The last year topminnow were found in Sharp Spring, in the San Rafael Valley, was 2001 (Voeltz and Bettaso 2003). Since 2001, no topminnow have been found despite one to two surveys annually there, while mosquitofish are usually numerous. Mosquitofish were first recorded

Table 1—Status of all natural Gila topminnow populations in the United States and Mexico. Sites in bold CAPS are ones where topminnow no longer occur (from Minckley 1999, Voeltz and Bettaso 2003, and USFWS files).

Site	Extant? ^a	Mosquitofish?
Bylas Spring S1	YES ^b	NO ^c
Cienega Creek	YES	NO
Coal Mine Spring	YES	NO
Cocio Wash	NO 1982	DRY
Cottonwood Spring	YES	NO ^d
Fresno Canyon	YES	NO ^e
Middle Spring S2	YES	NO ^{b,c}
Monkey Spring	YES	NO
REDROCK CANYON	NO 2005	YES^f
Salt Creek S3	YES	NO ^{b,c}
San Pedro River	NO 1976	YES
Santa Cruz River		
San Rafael	NO ^g	YES
Tumacacori	YES 2003	YES
SHARP SPRING	NO 2001	YES
Sheehy Spring	NO 1987	YES
Sonoita Creek	YES	YES

^a If no, last year recorded.

^b Renovated.

^c None recently, they have been recorded.

^d Recorded in spring run, never in head spring.

^e Recorded downstream, below barrier. Renovated to remove green sunfish in 2007 and is free of nonnatives; Sonoita Creek has many nonnatives.

^f Slated for renovation.

^g In Mexico 2006, United States in 1993.

here in the late 1970s. Sharp Spring contained a large and vigorous population of topminnow until mosquitofish accessed the system. Since 1995, I have observed the continual decline in the amount of aquatic habitat at Sharp Spring.

Redrock Canyon is the other natural topminnow population lost to mosquitofish since 1999. Redrock Canyon is significant for Gila topminnow conservation for two reasons: it is one of only two populations on public land (U.S. Forest Service) (Rinne and others 1980; Stefferud and Stefferud 1995), and it was the one remaining site that may have mimicked the historical expansion and contraction within basins and subbasins (Minckley 1999). A single topminnow was captured here in 2008 (Stefferdud and Stefferud 2008). Mosquitofish are still found in a small drainage from Cott Tank to Redrock Canyon where the last Gila topminnow was found; longfin dace *Agosia chrysogaster* are uncommon in lower Redrock Canyon although were common throughout the drainage before the 2000's. Reviews of management, condition, and fish surveys in the Redrock Canyon watershed can be found in Stefferud and Stefferud (1995), U.S. Bureau of Reclamation and U. S. Forest Service (2008), and U.S. Fish and Wildlife Service (1999:262-276). Redrock Canyon likely had more surface water historically, but has been dryer over the last decade (USBR and USFS 2008). The flow or extent of water in Redrock has not been regularly measured.

I believe that mosquitofish impacts on topminnow, in combination with long-term drought, was a factor in the extirpation of topminnow at Redrock Canyon and Sharp Spring. Long-term drought and climate change also appear to be a factor in the extirpation or reduction of other Gila topminnow populations (Bodner and others 2007; Duncan and Garfin 2006; Voeltz and Bettaso 2003).

Arizona State Parks collected water level data at Sharp Spring from 2000 to 2006 demonstrating reduced water quantity over time (unpublished). Though water levels were highly variable (fig. 1), there was an overall downward trend in water levels (fig. 1: trend lines). Of the 10 pools measured, 8 had downward trending water levels, one was static, and one had a slight upward trend. Seven pools went dry at some time, and all of those were also dry in the last two measurements (fig. 1:2005-2006). The flow or extent of water in Redrock has not been regularly measured. The best discussion of water in the Redrock system is the Bureau of Reclamations' and U.S. Forest Service's Redrock Barrier environmental assessment (USBR and USFS 2008).

In addition to many of the sites that were reestablished in the 1980s that were lost to desiccation (Minckley 1999; Simons 1987; Voeltz and Bettaso 2003), I believe Gila topminnow at Heron Spring, Johnson Wash Spring, and Willow Spring were extirpated (table 2) (Robinson 2010; Voeltz and Bettaso 2003), and populations at Cienega Creek reduced, due to drying caused or exacerbated by the current drought (Bodner and others 2007).

Heron Spring was stocked in 1981 with topminnow from nearby Sharp Spring (Voeltz and Bettaso 2003). Heron Spring is a small plunge pool that intercepts the locally high water table, with cienega conditions extending as outflow for about 100 m. Topminnow, though rare, were generally found in the plunge pool (Voeltz and Bettaso 2003) until 2007 when we captured no topminnow and measured dissolved oxygen at 1ppm (Ehret 2009). Gila topminnow can sometimes tolerate that little dissolved oxygen, but the oxygen may have been less than that before we measured it. The staff gauges maintained by Arizona State Parks there showed no decline in water levels (unpublished data). Discussions with others lead us to believe reduced subflow into the spring, floating vegetation covering the pond surface, and aquatic vegetation reducing outflow, combined to reduce dissolved oxygen until topminnow could no longer survive in Heron Spring.

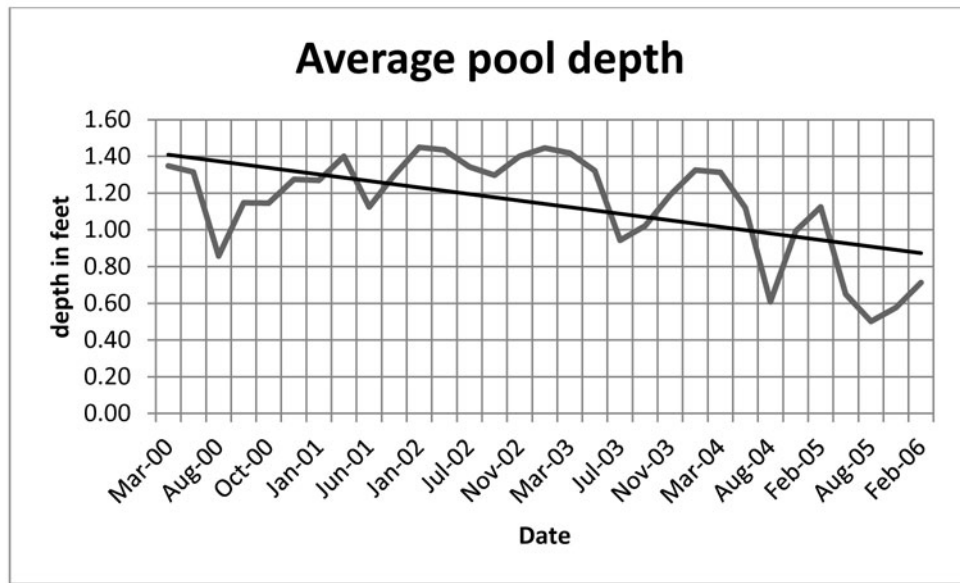


Figure 1—Averaged staff gauge measurements and trend line at Sharp Spring, Arizona (Arizona State Parks, unpublished).

Table 2—Status of some reestablished Gila topminnow populations in the United States. Site in bold CAPS is where topminnow no longer occur (from Minckley 1999, Voeltz and Bettaso 2003, and USFWS files).

Site	Extant? ^a	Mosquitofish?
HERON SPRING	NO 2006	NO
JOHNSON WASH SPRING	NO 2001	NO
Kayler Spring	YES 2004	YES
WATSON WASH	NO 1998	DRY^b
WILLOW SPRING	NO 2009 ^c	DRY

^a If no, last year recorded.

^b Well capped – mosquitofish present at capping.

^c Topminnow released in 2009.

Cienega Creek has the largest occupied topminnow habitat in the United States (Weedman 1999), though numbers in the upper perennial reach of Cienega Creek declined from 1989 to 2005 (Bodner and others 2007). The actual location of the first pool has moved downstream (Bodner and others 2007; personal observation) since about 2001, indicating reduced groundwater levels and subflow in that area. This has likely led to reduced dissolved oxygen in combination with more vegetation (trees shading the water surface, biological oxygen demand from decaying vegetation).

It appears that reduced volume and complexity of topminnow habitat, when combined with presence of mosquitofish, is more problematic for the persistence of topminnow, as opposed to the presence of mosquitofish alone. Therefore, since climatologists expect the southwestern United States to be warmer and drier (Seager and 2007), the impact of mosquitofish on topminnow populations is expected to be greater in the coming decades as topminnow habitat quality and quantity continues to decline.

Future Management

Actions to conserve and recover the Gila topminnow in Arizona and New Mexico are ongoing and additional actions are planned. Many new sites have been stocked with topminnow in the last 5 years (NMDGF and others 2010; Robinson 2010; USFWS and others 2007), and only time will tell if they persist. The involved management agencies and landowners will continue with stockings, under the Arizona Game and Fish Department Safe Harbor Agreement (AGFD 2007) and other mechanisms. They will also continue stream maintenance, habitat restoration, augmentation stocking, population and habitat monitoring, and outreach and education. Only vigorous conservation efforts can lead to the conservation and recovery of topminnow in the face of the threats they face. We are also exploring the use of topminnow in vector control programs in place of mosquitofish. Lastly, all attention must be given to reducing the use, populations, and movement of mosquitofish.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Native Aquatic Vertebrates: Conservation and Management in the Río Sonoyta Basin, Sonora, Mexico

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***Abstract**—The Río Sonoyta in northern Sonora is an important aquatic ecosystem that is disappearing because of drought and groundwater withdrawal. Its native species are also threatened by introduced species. The only watered reach is an intermittent segment (<1 km, Agua Dulce), found just across the International Border from Organ Pipe Cactus National Monument. The native fish present in the river include the endangered Sonoyta pupfish and the indigenous longfin dace. In the wild, the pupfish occurs only at Quitobaquito Springs and at Agua Dulce. The longfin dace may be extirpated. A partnership formed and led by the La Reserva de la Biosfera El Pinacate y Gran Desierto de Altar included partners from the United States and Mexico to create fish refuges in Mexico. We summarize conservation efforts to maintain native fishes in refuge ponds, report on their status, and offer suggestions for future management. We also present information on the future establishment of refuges for longfin dace and augmentation of pupfish refuges in the United States and Mexico. We briefly discuss the impact of a new wastewater treatment plant on the Sonoyta River.*

Introduction

The native aquatic vertebrates of the southwestern United States and northwestern Mexico are in trouble. This is particularly true for native fishes that have been recognized as endangered, threatened, or rapidly declining for decades, a trend also increasingly observed in many aquatic invertebrates, amphibians and reptiles (Hershler and Landye 1988; Miller 1961; Miller and others 2005; Minckley 1973; Minckley and Deacon 1991; Minckley and Marsh 2009; Rosen and Melendez 2010). These declines result from effects of introduced fishes, drought, and groundwater pumping, all of which dramatically affect native aquatic habitats. This paper presents information

on the recent conservation activities implemented for native aquatic vertebrates of the Río Sonoyta.

Description of the Río Sonoyta

The Río Sonoyta basin of Arizona-Sonora covers roughly 3,160 km² and was formerly a tributary of the Colorado River system. This former connection was diverted to the Sea of Cortez during the Pleistocene by the Pinacate lava flows (Donnelly 1974; Miller and Fuiman 1987). The drainage originates near the Sierra del Pozo Verde in Mexico, running northwest in Sonora and crossing into the United States where it turns west as Vamori Wash on the Tohono O'odham Nation. Vamori Wash then joins San Simon Wash, draining the western Tohono O'odham Nation and joining Sonoran parts of the basin as it crosses back into Mexico. It forms the Río Sonoyta near La Nariz. From there the river continues west through Sonoyta paralleling the border. The river then turns south along the east side of the Pinacate volcanic shield, passing through the eastern fringe of the Gran Desierto before reaching the Sea of Cortez east of Puerto Peñasco.

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Before the 19th and 20th centuries, perennial surface flow and cienegas occurred along portions of the river. Channel down-cutting in the mid 1800s degraded much of the upper drainage due primarily to groundwater pumping and livestock grazing (Hendrickson and Varela Romero 1989; Miller and Fuiman 1987; Rosen and others 2010; Shoenherr, 1988).

Today, the river continues this trend of degradation and desiccation, still driven by the burgeoning demands for water by an increasing human population (Hendrickson and Minckley 1985; Miller and others 2005; Minckley and Marsh 2009). Reduced perennial surface flow during summer (<1 km) is usually present in the privately owned Agua Dulce or “Papalote” reach 17 km downstream from Sonoyta, where flow is maintained by shallow groundwater discharge. The federal government considers the river channel federal land but has an agreement with the landowner to provide access to the property.

Río Sonoyta Fishes

Fish surveys of the Río Sonoyta have been well documented starting in the 1800s and continuing into the present (McMahon and Miller 1985; Miller and Fuiman 1987; Minckley and Marsh 2009; Rosen and others 2010; Snyder 1915). The only native fishes collected from this desert river have been the Sonoyta pupfish (*Cyprinodon eremus*) and longfin dace (*Agosia chrysogaster*) (Miller and others 2005; Minckley and Marsh 2009). The pupfish also occurs at Quitobaquito Spring, just across the International Border on Organ Pipe Cactus National Monument (QSWG 2011). The two pupfish populations have been isolated long enough to differ genetically and are managed separately (Loftis and others 2009). The Sonoyta pupfish is listed as endangered by the United States (USFWS 1986).

The longfin dace is a widespread and genetically diverse species, occurring in the Bill Williams, Gila, and Santa Cruz rivers of the United States, and in the Ríos Santa Cruz, de la Concepción, and Sonoyta in Sonora, Mexico (Minckley and Marsh 2009). The Ríos Sonoyta and de la Concepción populations display some overlap or gradation of morphological characters with populations of the more southern and easterly “*Agosia* sp.” in drainages to the east and southeast (Hendrickson 1987; Minckley and Marsh 2009; Tibbets 1993). The longfin dace is listed as threatened by Mexico (SEDESOL 2010).

Records of introduced fishes from the river include mosquitofish (*Gambusia affinis*), black bullhead (*Ameiurus melas*), and Gila topminnow (*Poeciliopsis occidentalis*) (Bagley 1997; McMahon and Miller 1985; Rosen and others 2010; Snyder 1915). An unidentified tilapia was reported in 2003 but not collected (Knowles 2010). The blue tilapia (*Oreochromis aureus*) has been introduced into the springs and pond at Ejido Quitovac, an isolated spring southeast of Sonoyta (this species may have been misidentified as *Tilapia zilli* in Rosen and others 2010). There are also commercial fish farms in the drainage near the town of Sonoyta, which reportedly raise some species of tilapia that have not yet been sampled or identified by any of the authors.

Recently, riverine populations of the Sonoyta pupfish have plummeted. Longfin dace, abundant in the system as recently as 2005, now appear extirpated from the river and have not been collected there since 2008 (Minckley and Izaguirre Pompa 2010; Rosen and others 2010).

Río Sonoyta Amphibians and Reptiles

There are six species of anuran amphibians (toads) in the Río Sonoyta valley and a population of endemic Sonoyta mud turtle

Kinosternon sonoriense longifemorale, a candidate species for listing under the U.S. Endangered Species Act (Knowles and others 2004; Rosen 2007; Rosen and others USFWS 2011). Little is known about the amphibians of this river or their use of it.

The Sonoyta mud turtle was once widespread in the Río Sonoyta watershed and is still common today at Quitovac and Quitobaquito Springs (Rosen and others 2010; Rosen and Melendez 2010). However, since downcutting of the cienega at Sonoyta and the advent of increased water pumping in the 1970s, populations of this endemic turtle have declined markedly. Currently, a population can be found in the sewage lagoon and associated wastewater effluent discharge from the town of Sonoyta (Rosen and others 2010). Populations of this turtle also occur at the Presa Xochimilco dam site in Sonoyta and in the wetted portion of Río Sonoyta at Agua Dulce (Rosen and others 2010). Small numbers of individuals have been found in the river at Santo Domingo and within 4 km upstream of Sonoyta.

Conservation Actions

The future plight of native fishes in the arid southwest was recognized by ichthyologists working on native fishes in the region by the 1940s (Minckley and Deacon 1991). The first recovery actions were also carried out by these individuals who moved fish they thought were in danger of extirpation to sites where they were protected from immediately obvious threats and believed likely to survive. Beginning in the 1960s and continuing to the present, government agencies have developed recovery programs that include natural sites and artificial refuges for listed fish species (Section V, Minckley and Deacon eds. 1991). By 1993, the Desert Pupfish Recovery Plan (USFWS 1993) listed over 100 attempts at establishing refuges, including the Sonoyta (Quitobaquito) pupfish (USFWS 1993). The U.S. Fish and Wildlife Service received internal funding to build pupfish refuges in northern Sonora in 2006. The USFWS Preventing Extinction grant was deemed necessary due to the on-going drought and groundwater pumping from the Río Sonoyta, which threatened to extirpate the Río Sonoyta population of the pupfish.

The design of the refuge ponds constructed in Sonora is based on the ideas and plans developed by individuals and agencies working on native aquatic vertebrate’s recovery in Arizona. The ponds are lined with a Geo-Pad™ polypropylene felt underliner covered by a 45 mil EPDM Pondguard™ liner, and are 3 by 4 M in area, hold ~ 5600 L of water and are ~1 M deep. Each pond has an inflow that passes through a short stream habitat before entering the main pond. Water is recirculated and leaves the pond through a filtered outflow, which is maintained using an electric pump. Pond substrate is fine sand and gravel. The refuge ponds were designed to accommodate both native fish species although the stream habitat was designed specifically to provide spawning habitat for the longfin dace.

Fish used to stock the ponds were obtained in 2007 from the Agua Dulce reach of the Río Sonoyta by seining and netting. Particular emphasis was placed on sorting the fish during capture and before stocking to prevent introduction of mosquitofish into refuges. Both species were collected and placed into coolers containing clean aerated water. Marine salts and a commercial conditioner were added to the water in all of the transport coolers to reduce the stress caused by handling and transport. The fishes were transported directly to the ponds, gradually acclimated to the pond water temperature, and stocked.

By 2011, five refuges were established and stocked with pupfish and longfin dace. In 2007, two refuge ponds were constructed at the Pinacate Biosphere Reserve headquarters and at the Centro Intercultural de Estudios de Desiertos y Océanos (CEDO) in Puerto Peñasco.

Fish were also stocked into the springs at Ejido Quitovac. The fourth refuge was completed and stocked in 2008, at the Colegio de Bachilleres del Estado de Sonora high school (COBACH) in the town of Sonoyta (López Méndez 2011); this pond also contains a Río Sonoyta mud turtle (introduced by students at the school). A fifth refuge was constructed in 2011 at the new Pinacate Biosphere Visitors Center by staff.

Conservation activities for the Sonoyta mud turtle are centered on salvage of turtles at Sonoyta from effluent waters that are, or will be desiccated as the antiquated sewage system of the town is updated. A cooperative agreement involving the Municipio of Sonoyta, local ejidos, the U.S. EPA (which is providing partial funding), and SEMARNAT, the Mexican national conservation authority, includes conservation considerations in the development of a new sewage treatment plant for the town of Sonoyta (Rosen 2009). This facility will have one or more ponds that will provide turtle habitat, which when combined with habitat created in the river channel by effluent discharge from the plant should allow this species to persist in Sonoyta. Once the sewage plant is operational the turtles present at the current sewage lagoon and near Presa Xochimilco will be salvaged and moved to the new facility. Water in the new effluent reach of Río Sonoyta may be suitable for establishment of native fishes as well (USEPA 2008).

Summary

Construction of refuge ponds for Río Sonoyta native fishes has been successful to date, and appears to have successfully secured small populations of the Río Sonoyta forms of Sonoyta pupfish and longfin dace. Today, pupfish are present in all of the ponds and a small population of longfin dace persists at the refuge at COBACH. As the water levels in Río Sonoyta continue to be unreliable—it is generally dry through most of its length and the remaining wetted portion has gone nearly or completely dry during recent droughts—these refuges are necessary to continue to provide a place to maintain these species for the foreseeable future. These habitats lack careful management and remain precarious due to silting in by blowing sand, maintenance issues, water supply issues, and funding for replacement of parts. If flows are returned to the river these refuge populations can be used to re-establish populations in their historical habitat.

In addition to construction of the refuge pond at COBACH, development of a curriculum using the pond as a research and study tool is in progress. Plans are to have the students explore different aspects of conservation, ecology, and aquatic biology using a hands-on approach, while managing their pond for the security and continued existence of endangered and threatened species. During the past year students have given presentations at the annual meeting of the Desert Fishes Council in Hermosillo, Sonora and at the 2012 Sonoran Desert Symposium. Future plans include community outreach to further raise awareness about the plight of native aquatic vertebrates and the Río Sonoyta.

There are also tentative plans to move between 200 and 500 individuals of both native fish species to refuges in the United States. The Sonoyta pupfish from Mexico would be used to provide immigrants into genetically bottlenecked populations of this species that were established in the United States in 1976 (AGFD 2001). Today, current refuges such as the one at Organ Pipe Cactus National Monument introduce wild individuals into their artificial refuge ponds to maintain genetic diversity. Longfin dace from the refuges would be used to establish a refuge population at the Arizona-Sonora Desert Museum as a hedge against extinction in Mexico.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Documenting the Biodiversity of the Madrean Archipelago: An Analysis of a Virtual Flora and Fauna

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Abstract—The Madrean Archipelago Biodiversity Assessment (MABA) of Sky Island Alliance is an ambitious project to document the distributions of all species of animals and plants in the Madrean Archipelago, focusing particularly on northeastern Sonora and northwestern Chihuahua, Mexico. The information is made available through MABA's online database ([madreal.org](http://www.madreal.org)). The sources of these records are museum collections, herbaria, scientific literature, other databases, observations, and field notes. Many observations come from MABA expeditions to isolated mountain ranges in northeastern Sonora involving taxonomic specialists, professors, students, and others from universities in Arizona and Sonora; and personnel from Mexican agencies. This paper provides an analysis of the current status of species records contained within the MABA flora and fauna databases and the significance of these records for future collection, research, and conservation planning.

Introduction

Project Background

Since 2009, the Sky Island Alliance's Madrean Archipelago Biodiversity Assessment (MABA) has been documenting the biodiversity of the Sky Island region with the aim of supporting conservation and scientific inquiry. The MABA project is a direct result of the Madrean Conferences held in 1994 and 2004. These conferences convened scientists and natural resource managers from the United States and Mexico to discuss the biodiversity and natural resources management of the Sky Island region (DeBano and others 1995; Gottfried and others 2005). One conclusion from these conferences was the lack of biodiversity data needed to support the management and conservation of the Madrean Archipelago, particularly in Mexico. Documenting the biodiversity of the Sky Island region is challenging, as the area contains over 50 mountain ranges/mountain complexes, hundreds of rare and localized species, and numerous habitats dispersed between the Rocky Mountains to the north, the Sierra Madre Occidental to the south, and the Sonoran and Chihuahuan deserts to the west and east. Sky Island Alliance worked with programmer Ed Gilbert, the

SEINet flora database, Symbiota, and the Veolia Foundation to create the MABA online database (<http://www.madreal.org>); since its creation, the database has become a large repository of information for many groups of species in the Sky Island region and includes both vouchered specimens and observations from herbaria, museum collections, scientific literature, and MABA's own field expeditions. This paper provides an analysis of the current status of species records contained within the MABA flora and fauna databases and the significance of these records for future collection, research, and conservation planning.

Virtual Flora and Fauna

The MABA online database is considered a "virtual flora and fauna," a type of digital resource that is revolutionizing the way biodiversity information is documented and shared. Floras and faunas refer to both the species of plants and animals that inhabit a region as well as the publications that describe them (Heidorn 2004). Historically, floras and faunas have taken the form of print media and contain information such as scientific classifications, species descriptions, illustrations, photos, distribution maps, and identification keys. There are limitations to printed media when it comes to documenting biodiversity, not least of which are the sheer number of organisms in some taxonomic groups; given that there are an estimated 5,300 species of flowering plants in Madrean Pine-Oak Woodlands (Conservation International 2011), a print flora for the entire region would be impractical. Additionally, the cost and labor associated with publishing regional floras and faunas also limit production and distribution of these works; in 2003 the estimated cost of producing a flora with 2,104 species was \$1,579,946 (Heidorn 2004).

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Web-based virtual floras overcome many of these problems: they are less expensive, support unlimited images and species records, allow for complex data queries, and can be corrected and updated continually (Gilbert, unpublished presentation). Web-based flora and fauna have taken databases, once the private domain of individual researchers, and have extended them to be a medium for collaboration between researchers and citizen scientists (Schnase and others 1997). Finally, web-based floras and faunas increase the speed at which biodiversity data is collected and made available, a critical factor considering how quickly species and habitats are being lost to human activities (Heidorn 2004).

The last two decades have seen a worldwide effort to digitize herbaria and museum collections, resulting in flora and fauna databases containing on the order of 10^4 and 10^6 records (Soberón and others 2002). Access to such large datasets has spurred the burgeoning field of biodiversity informatics (Soberón and Peterson 2004), and has led to scientific applications such as modeling species ranges and evolutionary analyses (Peterson and others 1999; Zhong 1999); locating areas for biodiversity exploration (Jones and Gladkov 1999; Soberón and others 2004); prioritizing for protected areas (Godown and Peterson 2000; Kelley and others 2002), and modeling routes for the spread of invasive species (Higgins and others 1999; Peterson 2004).

No matter how sophisticated the design of a virtual flora or fauna, it is only as good as the data it contains. A database with a comprehensive set of species records allows for comparison of species lists across sites; observation of species richness over time, including before and after habitat modifications; and analyses such as those mentioned in the previous paragraph (Soberón and others 2004). Adding records to the MABA database has been ongoing since the program began in 2009. This research reflects the status of the MABA database through analyzing species records in reference to Sky Islands/complexes, reporting the sources of records, and identifying which time periods have been the most productive for collection efforts. The results of this paper are useful for targeting areas for future collection and data acquisition efforts and better understanding how the MABA database can be used for research and conservation planning.

Methods

Defining Sky Island Ranges and Complexes

In order to perform count and density analyses on species data for each Sky Island/complex, a GIS polygon layer was created defining the physiographic boundaries of each range or complex containing oak woodland. Generally, the boundaries of ranges or complexes were digitized using physiographically defined mountainous features containing contiguous or closely clustered areas of oak woodland that were isolated from the main Sierra Madre and Rocky Mountains. Previously created maps of the region have classified Sky Islands exclusively on the presence of vegetation (Marshall 1957; Brown and Lowe 1980). Range/complex borders were defined by drawing along a 7 percent slope gradient threshold (see fig. 1). In areas of ambiguous slope, borders were drawn to include 50 percent or greater digital elevation model (DEM) cells with a 7 percent slope gradient or higher. These boundaries emphasize the physiographic continuity of complexes or ranges, including areas outside of the oak woodland boundaries that are still mountainous. Physiographic ranges and complexes were subdivided when they showed significant gaps in oak woodland presence. These divisions were drawn along low points of elevation in those gaps. Additionally, two ranges that did not show oak woodlands in the Geographic Information System (GIS) vegetation database used in this analysis, the Mule Mountains



Figure 1—This image shows areas above 7 percent grade (white) that were used to help digitize the boundary of Sky Island ranges and complexes.

and the Cerro Cobachi, were included based on the field experience of Dr. Tom Van Devender. A small number of ranges and complexes that show oak woodland connections to the Sierra Madre were included in this analysis because of historical precedent. These “peninsulas” of the Sierra Madre are noted in table 1.

Names of complexes were determined by combining the northernmost and southernmost range names. Range names were acquired from U.S. Geological Survey (USGS, 2002) and Mexican National Institute of Statistics and Geography (INEGI) topographic maps. In some cases, a more commonly known name was chosen over the naming convention above. A single unhyphenated name was used for isolated ranges and smaller subdivisions of Sky Island complexes. Figure 2 provides a map of the Sky Island ranges/complexes used in this analysis.

Data Acquisition and Manipulation

Species point locations and associated data were obtained by SQL queries to the separate MABA flora and fauna databases. Queries were made using a web-based MySQL interface to facilitate downloading large datasets; however, the same data can be accessed using the MABA online database (<http://www.madrean.org>). Latitude and longitude coordinates bounded queries to a region containing Arizona, New Mexico, Sonora, and Chihuahua. Records lacking geographic coordinates were eliminated. Each acquired dataset was then imported into a GIS and projected into the Albers Conformal Conic projection using the NAD 83 datum. A spatial join was then created to link species data with Sky Islands/complexes boundaries.

Queries were made for the six separate classes of animals: Arthropoda, Aves, Mammalia, Osteichthyes, Amphibia, and Reptilia. Amphibia and Reptilia classes were then combined. For plant records, the entire database was downloaded and classified by family name into three separate datasets for angiosperms, gymnosperms, and ferns

Table 1—Species records by Sky Island or Sky Island complex.

Sky Island/Complex Name	Area (sq km)	Total Animals	Animal Density ^a	Total Plants	Plant Density ^b	Amphibia-Reptilia	Arthropoda	Aves	Mammalia	Osteichthyes	Angiosperms	Asteraceae	Poaceae	Fabaceae	Gymnosperms	Ferns and Allies
ALAMO HUECO	99	0	0.00	80	0.81	0	0	0	0	0	77	12	16	4	0	3
ANIMAS ^b	543	1	0.00	1221	2.25	1	0	0	0	0	1170	226	183	117	31	20
BIG HATCHET	153	0	0.00	112	0.73	0	0	0	0	0	108	8	3	12	1	3
COYOTE - BABOQUIVARI	552	9	0.02	3065	5.56	8	0	0	1	0	2865	463	429	312	17	183
DOS CABEZAS - CHIRACAHUA	1,630	10	0.01	10871	6.67	4	0	0	6	0	10265	2123	1231	958	314	292
DRAGOON	180	1	0.01	1274	7.08	0	1	0	0	0	1120	150	204	100	25	129
GALIURO	1,500	56	0.04	2136	1.42	12	2	37	3	2	2057	275	191	238	29	50
HUACHUCA - PATAGONIA	1,083	174	0.16	10930	10.09	71	64	12	6	21	10122	1999	1506	967	230	578
LITTLE DRAGOON	84	0	0.00	143	1.71	0	0	0	0	0	136	20	29	26	0	7
LITTLE HATCHET	115	0	0.00	169	1.47	0	0	0	0	0	165	24	34	15	1	3
MULE	335	10	0.03	3835	11.46	10	0	0	0	0	3710	642	193	448	50	75
PELONCILLO	618	5	0.01	227	0.37	2	1	0	1	1	222	35	22	19	1	4
PERILLA	192	14	0.07	209	1.09	4	10	0	0	0	202	29	38	18	1	6
PINALEÑO	829	6	0.01	5053	6.10	0	0	0	3	3	4714	725	658	307	165	174
RINCON	877	5	0.01	4854	5.53	0	2	0	3	0	4614	656	907	463	28	212
SANTA CATALINA	770	5	0.01	9989	12.97	0	2	0	3	0	9341	1610	1170	908	175	473
SANTA RITA	811	11	0.01	6737	8.31	3	2	0	4	2	6430	1152	929	762	86	221
SANTA TERESA	954	0	0.00	1818	1.91	0	0	0	0	0	1725	233	253	157	31	62
SIERRITA	148	0	0.00	117	0.79	0	0	0	0	0	109	16	35	6	2	6
SWISSHELM	133	37	0.28	218	1.64	0	37	0	0	0	211	41	9	29	3	4
TORTOLITA	132	1	0.01	80	0.61	0	0	0	1	0	76	8	9	7	2	2
WHETSTONE	210	35	0.17	577	2.75	3	0	32	0	0	546	88	99	47	12	19
WINCHESTER	288	0	0.00	79	0.27	0	0	0	0	0	78	20	2	6	1	0
ACONCHI	2,267	560	0.25	288	0.13	54	66	427	3	10	274	37	18	66	2	12
ANIBACACHI	102	10	0.10	853	8.40	10	0	0	0	0	816	116	122	86	3	34
ATASCOSA - CIBUTA	2,443	570	0.23	5218	2.14	87	6	428	6	43	4955	753	681	686	34	229
BATAMOTE	37	0	0.00	0	0.00	0	0	0	0	0	0	0	0	0	0	0
CERRO COBACHI	261	5	0.02	14	0.05	0	0	0	5	0	14	3	0	6	0	0
CERRO EL TIZNADO	370	31	0.08	17	0.05	4	0	27	0	0	17	1	1	8	0	0
CERRO HUEQUECHI	241	19	0.08	145	0.60	6	0	7	0	6	139	15	16	20	1	5
CHIVATO	340	68	0.20	61	0.18	0	0	67	0	1	58	2	6	6	3	0
EL CARMEN - VERDE	2,702	234	0.09	413	0.15	60	0	154	2	18	408	46	24	128	2	3
EL GATO ^b	1,243	741	0.60	779	0.63	67	174	465	29	6	667	74	26	75	64	48
EL HUMO	122	115	0.94	172	1.41	1	0	114	0	0	169	21	26	19	0	3
EL MANZANAL	980	41	0.04	393	0.40	12	5	4	0	20	390	53	54	57	2	1
EL MAVIRO	412	158	0.38	438	1.06	97	0	39	5	17	434	43	15	136	0	4
EL PAJARITO - LA CAÑADA	441	139	0.32	98	0.22	5	20	110	1	3	98	19	3	22	0	0
EL PINITO	944	556	0.59	337	0.36	272	53	219	0	12	316	40	46	44	0	21
EL TIGRE ^b	3,277	1476	0.45	1768	0.54	428	55	927	28	38	1645	222	145	198	91	32
ENMEDIO	129	0	0.00	0	0.00	0	0	0	0	0	0	0	0	0	0	0
LA HUERTA	525	301	0.57	177	0.34	195	2	88	0	16	177	7	6	56	0	0
LA MADERA - CUCURPE	806	309	0.38	585	0.73	22	43	240	4	0	567	59	49	94	11	7
LAS CALABAZAS - MARTINEZ	560	72	0.13	302	0.54	7	3	61	1	0	297	30	6	80	0	5
LAS GUIJAS - LA SEÑORITA	1,414	171	0.12	77	0.05	9	15	130	6	11	77	6	10	13	0	0
LOS AJOS - LA MADERA	5,094	2091	0.41	2646	0.52	347	373	1330	35	6	2452	303	199	350	140	54
LOS CABALLOS	600	52	0.09	157	0.26	3	6	31	2	10	157	7	2	40	0	0
MARIQUITA - ELENITA	334	625	1.87	401	1.20	7	45	571	2	0	315	57	28	22	84	2
MAZATÁN	174	61	0.35	158	0.91	15	45	0	1	0	137	50	24	20	0	21
PELONCILLO - PAN DURO ^b	3,198	3069	0.96	4443	1.39	408	357	2185	14	105	3934	549	494	384	451	58
SAN ANTONIO - AZUL	2,147	942	0.44	1776	0.83	55	113	733	35	6	1666	185	149	151	81	29
SAN JAVIER	360	290	0.81	1007	2.80	26	173	91	0	0	969	143	33	160	0	38
SAN JERONIMO - LA CABRERA	475	12	0.03	267	0.56	0	0	5	2	5	265	26	16	71	0	2
SAN JOSE	85	51	0.60	105	1.24	1	0	50	0	0	95	8	8	8	9	1
SAN JUAN	214	0	0.00	2	0.01	0	0	0	0	0	2	0	0	1	0	0
SANTO NIÑO - LA CAMPANERIA	627	129	0.21	243	0.39	10	8	106	5	0	243	28	4	63	0	0

^aDensity was calculated by dividing the number of records by the area in square meters.

^bIndicates that the range or complex has a direct oak woodland connection to the Sierra Madre.

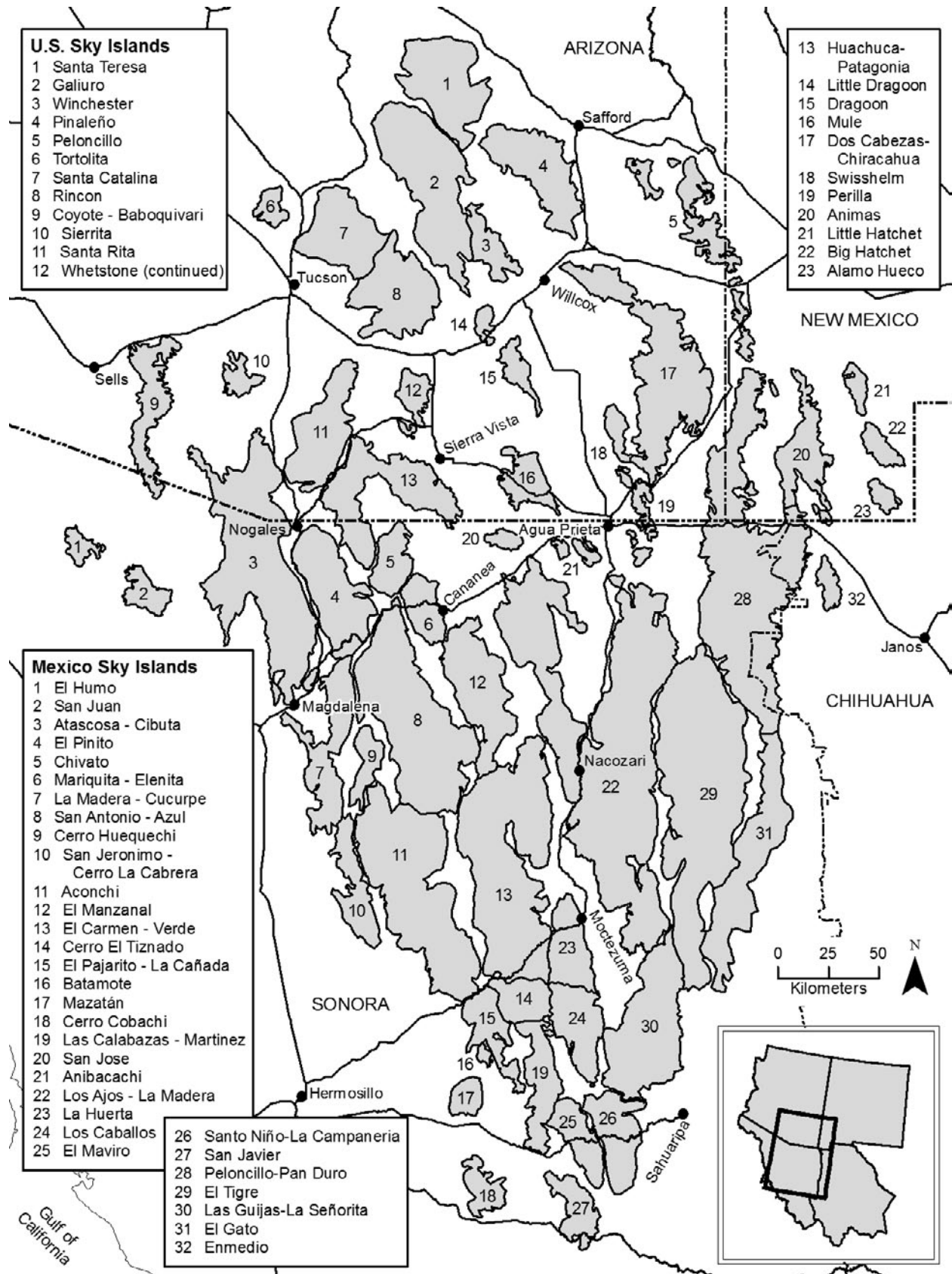


Figure 2—Map depicting the Sky Island ranges and complexes used to the distribution of species record data in the Madrean Archipelago.

and fern allies. Observations of members of the families Asteraceae, Poaceae, and Fabaceae were then isolated from the angiosperm data. Analysis of contributing institutions and record collection dates was performed using data downloads from separate SQL queries. This separate analysis contained some discrepancies between the two querying efforts. This may be attributed to the addition of new sets of data since the first queries were performed.

The Nature Conservancy's Apache Highlands Ecoregion conservation priorities analysis provided vegetation data for Arizona, New Mexico, and northern Sonora and Chihuahua (Marshall and others 2004). This data combined Gap Analysis Program (GAP) vegetation data for areas in the United States with Forest Inventory 2000 layers for areas in Mexico. As this data terminates in the middle of Sonora, data for more southern regions was acquired from an INEGI layer entitled "uso del suelo y vegetación" (2005). Additionally, a digitized layer of Brown and Lowe's Biotic Communities of the Southwest classification map (1980) was used to supplement the more modern, digitally mapped layers. Where oak woodland data differed between sources, the combined area of oak woodlands in all layers for the given region was used to define Sky Islands/complexes. Digital elevation model (DEM) data used to create the slope analysis layer is a stitched mosaic of 90 m resolution raster imagery from NASA's 2000 Shuttle Radar Topography Mission (USGS 2002).

Results

General Statistics

A total of 596,681 plant and 121,355 animal records with geographic coordinates were queried from the MABA flora and fauna databases for the States of Arizona, New Mexico, Sonora, and Chihuahua. Of these records, 87,134 plant and 13,278 animal records were identified within the Sky Island/complex polygons created for this analysis. These figures represent only 14 percent of all records within the states mentioned. However, as the Sky Islands/complexes only comprise 4 percent of the area of those states, these figures show a greater number of records within Sky Islands/complexes. Across all Sky Islands/complexes, the average sampling effort (the number of records/area in km²) for plants was 2.18 records/km² and 0.22 records/km² for animals, representing a tenfold difference in sampling effort between the MABA flora and fauna databases. When sampling effort was compared between Sky Islands/complexes in Mexico versus the United States, the results differed between the animal and plant records. Note that the country label of Sky Islands/complexes that straddled the border refers to the location of the polygon's centroid. Plants were better represented in the United States with an average sampling effort of 3.98 records/km² compared with 0.87 records/km² in Mexico. Animals were better represented in Mexico with an average sampling density of 0.35 records/km², while the United States had an average of 0.04 records/km². Table 1 provides an overview of the data generated in this analysis.

Contributing Institutions

The databases were analyzed to better understand where the majority of records originated. Twenty-two institutions contributed to the MABA flora database. The University of Arizona Herbarium contributed the most records, followed by the Arizona State University Herbarium, MABA observations, Sonoran Desert Plants: An Ecological Atlas, and the Desert Botanical Garden. Thirty-six institutions contributed to the MABA fauna database. MABA contributed 13,198 records, by

far the greatest number of observations, followed by the University of Arizona, Arizona State University, eBird, and the University of Texas at Arlington. Figure 3 shows the distribution of records among contributing institutions.

Temporal Distribution of Records

Examining collection dates for species records revealed that both the MABA flora and fauna databases were right skewed (fig. 4) toward more modern collection dates. Seventy-five percent of all plant records were collected after 1962 while the same percentage of animal records was collected after 1976. The earliest plant record in the database was an *Acacia texensis* collected by G. Thurber in 1851. The earliest animal record was a *Rana yavapaiensis* collected by Edgar A. Mearns in 1893.

Within the MABA flora database, most ranges/complexes show recent collection efforts; however, it appears that the Cerro Cobachi, Sierrita, Big Hatchet, El Maviro, Las Calabazas-Martinez, and Santo Niño ranges have not seen collection efforts since the late to mid-1990s. Fewer ranges within the MABA fauna database show recent collection efforts; the Sierrita, Tortolita, Pinalaño, Cerro El Tiznado, Mule, Cerro Cobachi, and Animas ranges do not show any new records since the late 1990s, and the Sierrita, Tortolita, and Pinalaño ranges do not show any records since the late 1970s. It should be noted that the Sierrita range only showed two animal records revealed in a later query of the database. The statistical mode of record collection dates was calculated for each individual Sky Island/complex for flora and fauna records separately. For plant records, 14 of the 33 Mexican Sky Islands/complexes had modes more recent than 2000, while only 4 of the 22 United States Sky Islands/complexes had modes more recent than 2000. This indicates that sampling efforts in Mexico have been more vigorous recently than those in the United States. For animal records, 12 of the 33 Mexican Sky Islands/complexes had modes more recent than 2000, while only 3 of the 22 United States Sky Islands/complexes had modes more recent than 2000. As with plant records, this shows that the collection effort for Mexico has been more vigorous recently.

Records by Taxa

The databases were queried based on major taxonomic groups to better understand which groups were better sampled; conversely, this analysis also revealed which Sky Island ranges/complexes have the fewest number of records. In terms of overall records (both animals and plants), the Huachuca-Patagonia complex yielded the most records with 11,104 observations. Not surprisingly, other ranges/complexes with large numbers of records were the Dos Cabezas-Chiracahuas (10,881 records), the Santa Catalinas (9,994 records), the Peloncillo-Pan Duros (7,512 records), and the Santa Ritas (6,748 records). The most poorly represented ranges/complexes were Batamote, Enmedio, San Juan, Cerro Cobachi, and Cerro El Tiznado. Of these, Batamote and Enmedio had no records and the remainder all had fewer than 50 records.

The animal taxa queried in the MABA fauna database were Arthropoda, Aves, Mammalia, Osteichthyes (bony fish), and Amphibia/Reptilia. There were more records for Aves than for any other class of animals with 8,690 records, followed by Amphibia/Reptilia (2,326 records), Arthropoda (1,683 records), Osteichthyes (362 records) and Mammalia (217 records). The top five ranges/complexes for Arthropoda were the Los Ajos-La Madera, Peloncillo-Pan Duro, El Gato, San Javier, and San Antonio-Azul. Of the 55 ranges/complexes identified

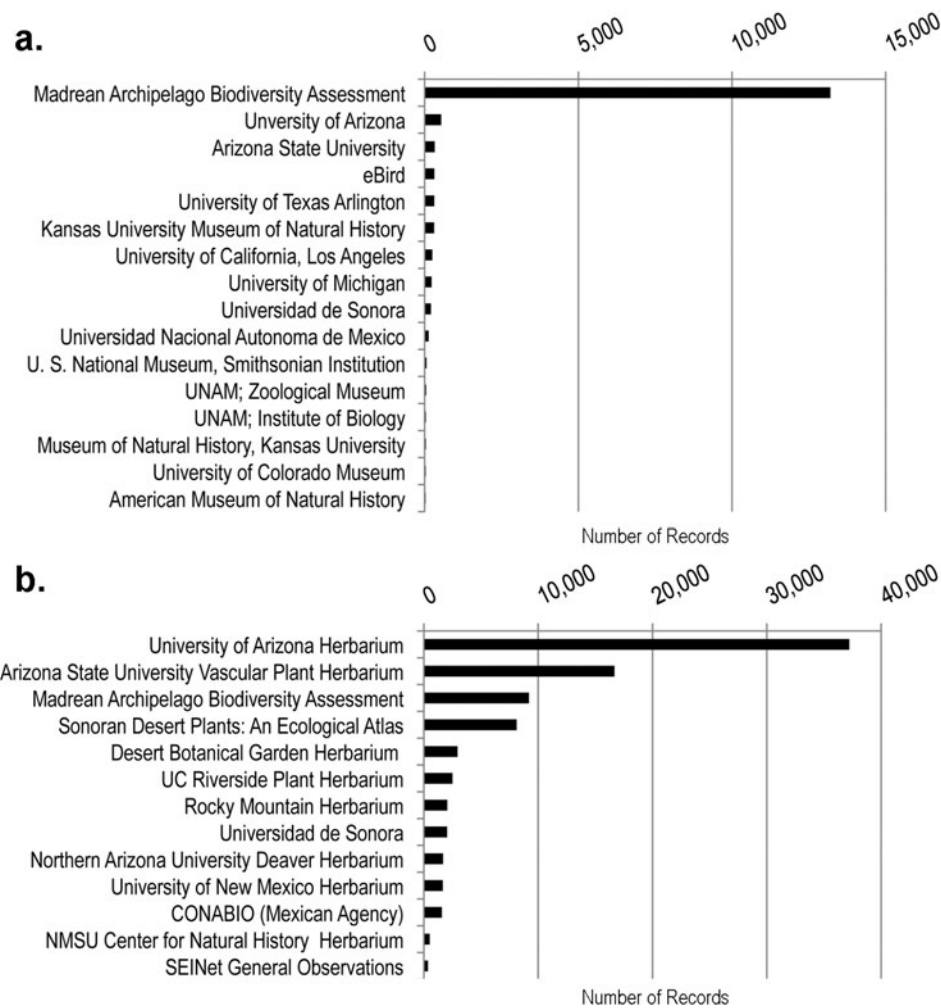


Figure 3—Major contributing institution for the MABA fauna database (a) and the MABA flora database (b). Note: not all contributing institutions are depicted here.

here, 40 have 10 records or fewer. The top five ranges/complexes for Aves were the Peloncillo-Pan Duro, Los Ajos-La Madera, El Tigre, San Antonio-Azul, and Mariquita-Elenita. While Aves was better represented than other taxa, 29 ranges/complexes remain without bird records. For Amphibia and Reptilia combined, the best-represented ranges/complexes were El Tigre, Peloncillo-Pan Duro, Los Ajos-La Madera, El Pinito, and La Huerta. Thirty-eight ranges/complexes had 10 or fewer records for reptiles and amphibians. Osteichthyes and Mammalia showed very few records, so comparisons between ranges are excluded here (see table 1).

The plant groups queried in the MABA flora database were the divisions for angiosperms, gymnosperms, and ferns and fern allies. Angiosperms were further divided into the families Asteraceae, Poaceae, and Fabaceae. All divisions had several thousand records each. Angiosperms were best represented with 81,861 records (expected since angiosperms include many more species than other groups), followed by ferns and fern allies (3,135 records) and gymnosperms (2,183 records). The angiosperm families were represented with 13,458 Asteraceae, 10,361 Poaceae, and 8,996 Fabaceae. Gymnosperms were least well represented with 34 ranges/complexes having fewer than 10 records, while ferns and fern allies reflected 31 ranges/complexes with fewer than 10 records. Angiosperms had at least 10

records in all ranges except 3: San Juan (2 records), Batamote, and Enmedio. Of the 55 Sky Island ranges and complexes, only 9 had records for each taxonomic group (both animals and plants); these were the Huachuca-Patagonias, Atascosa-Cibutas, Peloncillo-Pan Duros, Los-Ajos-La Maderas, Galiuros, San Antonio-Azuls, El Tigre, El Gato, and Aconchi.

Discussion

Biodiversity databases that are “extensive and exhaustive” are important because they allow for the application of biodiversity data to basic research and conservation planning purposes (Soberón and others 2004). This analysis was designed to help the Sky Island Alliance’s MABA program better understand the strengths and weaknesses of its flora and fauna biodiversity databases, and to inform the next steps to improve the coverage and quality of species data. It is also an opportunity to consider how these data can be applied for conservation planning purposes.

Specimen records are typically biased by the spatial and temporal distribution of collection efforts (Soberón and Peterson 2004; Soberón and others 2004). Biases in species location data are often attributed

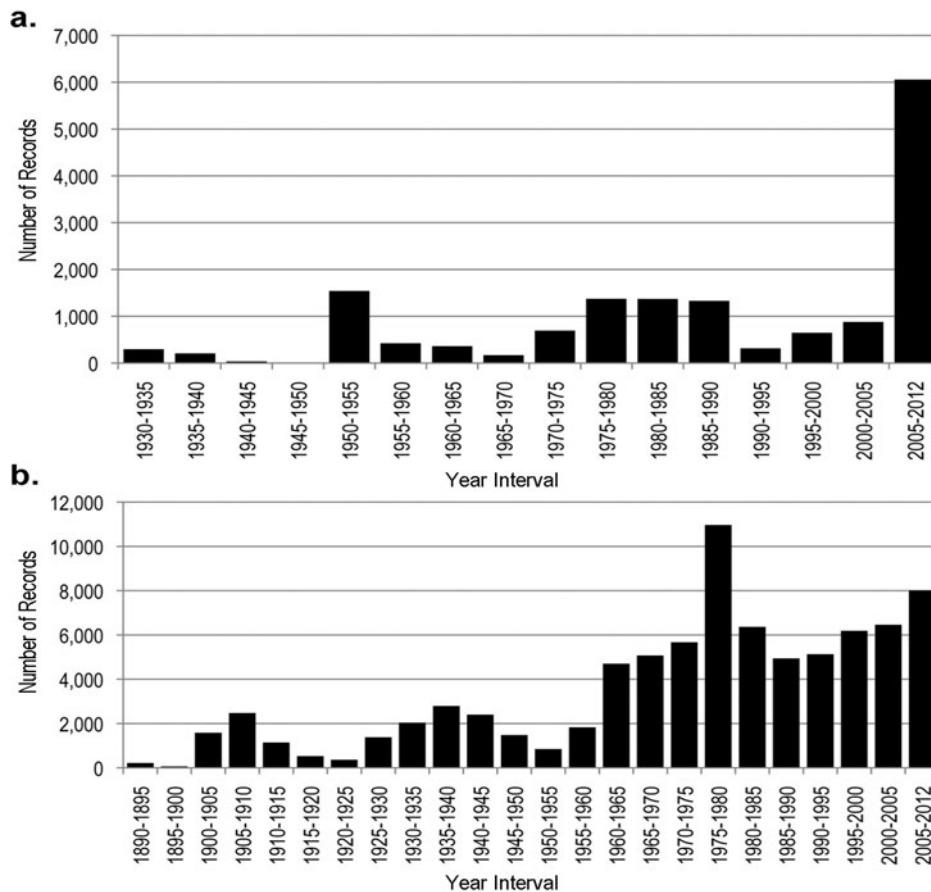


Figure 4—The distribution of species records collection dates for 5-year intervals for the MABA fauna database (a) and the MABA flora database (b).

to proximity to roads, research stations, educational institutions, land tenure, and cities (Soberón and others 2000). This analysis revealed that many Sky Islands and complexes have no or very little species data; only nine ranges contained records for all of the taxonomic groups queried here. Additionally, there remains a large disparity in sampling effort between the United States and Mexico. Plants are better represented in the United States by a factor of nearly five to one, which is likely due to actual sampling effort because of the large network of herbaria that have provided data. Animal records are better represented in Mexico by a factor of eight to one. This discrepancy along with the overall better representation of plants in the database indicates that a large number of existing animal records in museum collections are not included in the MABA database. Therefore, adding additional animal collections from museums and other sources to the MABA database should be a priority. Additionally, any Sky Islands/complexes lacking in species data across multiple groups of taxa should be considered for future field collection efforts.

Biodiversity databases rely on the species collections contained in museums and herbaria. Natural history data may become antiquated and less useful for contemporary applications if collections are not continually updated (Peterson and others 1998; Winker 1996). At first glance, the distributions of record collection dates appeared to be relatively contemporary, with 75 percent of records being collected in the last 50 years. However, this does not account for biases in the collection of individual taxa, which may occur when institutions receive funding to study specific taxonomic groups or when certain

taxa are treated with particular interest in a given period (Soberón and others 2004). Individual Sky Islands/complexes that do not contain records from recent years are due for new collection efforts.

The importance of continuing the collection and compilation of species data cannot be understated. Species records from herbaria, museum collections, and other sources are the foundation of our understanding of the biodiversity of the planet and how to conserve it (Winker 1996). While there are remote sensing methods for assessing areas for high biodiversity and conservation priority, the failure to include species data in these analyses may leave unique and vulnerable species unprotected (Brooks and others 2004). Furthermore, increased access to species data through online databases like MABA's, as well as the huge increase in other sources of environmental data, has led to innovative methods of modeling species distributions for researching biodiversity and conservation planning purposes (Lobo and others 1997; Jones and Gladkov 1999; Soberón and others 2004; Rebelo and Siegfried 1992; Csuti and others 1997; Godown & Peterson 2000; Peterson and others 2000; Kelley and others 2002; Burgess and others 2002; Chen & Peterson 2002). Combining species data with data on climate, physiography, and other characteristics allows the modeling of ecological niches (Soberón and Peterson 2004). The use of these methods would help overcome some of the gaps and biases in species data now available for the Sky Island region and contribute to a better understanding of conservation priorities in the region.

However, before data can be used for the applications mentioned above its quality must be assessed. Large mixed source databases

such as MABA's often face difficulties in maintaining data quality. The errors in most need of review are those related to taxonomy and incorrect georeferencing. Taxonomic errors are somewhat mitigated by taxonomic thesauruses that check for antiquated scientific names, a continual challenge in a world of rapidly changing taxonomy. The correction of georeferencing errors is more laborious and requires cross-referencing species' locality descriptions with their geographic coordinates (Soberón and others 2002); although there are some statistical tools available to help with this process (Chapman and Busby 1994). Some assurance of quality control would improve the confidence with which researchers and lay people could use MABA data. Without quality control measures,

The MABA project has made great strides in compiling biodiversity data within the Madrean Archipelago, both from existing collections and from field collection efforts. There still remain numerous gaps in the biodiversity data available for the region, further emphasizing the need for more collection efforts. Despite the lack of data for specific areas, there remains a great deal of data that is available for conservation and research efforts. Understanding the biodiversity of the Madrean Archipelago will help highlight the uniqueness of the region and protect its species for future generations.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Restoration

Agricultural Field Reclamation Utilizing Native Grass Crop Production

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Abstract—Developing a method of agricultural field reclamation to native grasses in the Lower San Pedro Watershed could prove to be a valuable tool for educational and practical purposes. Agricultural field reclamation utilizing native grass crop production will address water table depletion, soil degradation and the economic viability of the communities within the watershed. The focus of this study was to analyze the conversion of agricultural fields to native grass crops of three representative sites. Study sites include; a farm with fields that were seeded and allowed to grow for a period of time with subsequent termination of irrigation, a ranch that converted approximately 18 acres to native grasses for production of grass-fed beef and a ranch that is working towards a goal of restoring the giant sacaton habitat. Each site was analyzed utilizing a matrix of questions. Personal interviews and site visits were sources for information to complete the matrix. Conclusions were drawn through analysis of the matrix and recommendations developed to formulate the reclamation method most appropriate to achieve the anticipated goals of each site. This study developed a recommended method for agricultural field reclamation to native grasses in the Lower San Pedro Watershed to be used as a tool for educational and practical purposes utilizing the information obtained. The recommended method includes the processes for initial plan development, field preparation, and seeding. The methods are discussed within the project and prepared as an educational flier.

Introduction

Water table depletion, soil degradation and economic viability are major issues in the borderland agricultural communities located in Southern Arizona and Northern Mexico (Anderson and others 2006). Agricultural production of cotton and alfalfa, traditional commercial crops, results in lower water tables and reduced flows in related rivers with the ultimate impact on future sustainability of the region (Anderson and others 2006). The Sonoran Desert, located in Southern Arizona and Northern Mexico, has several river systems and related watersheds in the United States and Mexico impacted by water table depletion and the adverse effects of extensive high water use agriculture (Collins and Bolin 2007).

Traditional agricultural crops require substantial amounts of water with the resultant water table drawdown. Agricultural practices utilizing traditional commercial crops are not sustainable in the San Pedro River Watershed as they exceed the recharge capacity of the aquifer with the result of reduced flow in the river (Morehouse and others 2008). The deterioration of the riparian area related to the river is jeopardizing indigenous species of flora and fauna, such as the Southwestern Willow Flycatcher (*Empidonax traillii extimus*) that is on the endangered species list (Price and others 2005; U.S. Fish and Wildlife Service 1995).

The goal of this study is to develop a plan and process to reclaim agricultural fields to native grasses within the study area. Many attempts have been made at field reclamation with varying degrees of success. Literature review, farm manager interviews, and site analysis were incorporated into the plan analysis and development. The goal of the study is to provide a prescription for successful field reclamation.

Background

The Lower San Pedro River has experienced decreased flow due to irrigation, mining, stock grazing, public water supply, and domestic and commercial/industrial wells. Drawdown increased from 10,000 acre-feet per year in the 1940s to more than 60,000 acre-feet per year in 1990 (Katz and others 2009). The reclamation of agricultural fields to native grasses will decrease water use, therefore, allowing the restoration of the water table and increase flow in the river and improvement in the related habitat (Baker n.d.). To encourage change from traditional crops to native grasses, it is essential to document the scientific aspects of the conversion. Literature review and site inspections show that many small pieces of the bigger puzzle exist but a comprehensive document that accurately describes the details is lacking. A comprehensive document that establishes the procedure for change will enable stakeholders to make value judgment, educators to have a tool for demonstration and activist supportive research.

The primary research question that this study addresses is how to approach the reclamation of agricultural fields to native grasses and ensure long term success. The objective of the study was to look at three sites within the Lower San Pedro River watershed, review supporting literature, and document the results. The development of a reclamation process will provide a guide that allows for successful reclamation of agricultural fields to native grasses. The encouragement for stakeholders to convert to native grasses must be supported with

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evidence that it is an economically viable process for the present and the future.

The initial fact finding started with a visit to the Natural Resources Conservation Service (NRCS) office in Tucson and an interview with Ms. Kristen Egen, District Conservationist, in November of 2010. Ms. Egen provided the standard procedure available from the NRCS for the process of planting native grasses in the region. The process includes research involving historic vegetation and soil analysis utilizing the U.S. Department of Agriculture (USDA) NRCS Soil Survey website. The preceding information allows determination of the historical grasses in the area and, with that, a selection for the development of the seed mix to be used. The NRCS website (<http://websoilsurvey.nrcs.usda.gov>) is an important resource in the process of field conversion with information about soil type and recommended grasses for the area under question.

Study Sites

Three representative sites within the San Pedro Watershed were selected for the study: Black Farm Preserve (BFP) owned by the Salt River Project (SRP), Camp Stool Ranch (CSR) owned by the Mercer Family, and Cobra Ranch (CR) owned by The Nature Conservancy (TNC). These sites were chosen on the basis of known qualities including available data, access to the site, and available information and they represent a cross section of sites within the watershed. Interviews and site visits along with written documentation of events on the sites compose the majority of information documented for the results analysis (table 1).

Black Farm Preserve (BFP) is owned by the Salt River Project and managed by The Nature Conservancy. The fields planted to native grasses totaled 101 acres. Ruth Valencia, Senior Environmental Scientist for SRP, provided information concerning BFP and the methods used for conversion to native grasses and the subsequent results. SRP worked with the Tucson Plant Materials Center staff for development of the seed mix to be utilized at the BFP. Interviews with Dan Wolgast,

the farm manager at BFP, and Molly Hanson with TNC Lower San Pedro River Program provided additional information concerning the process of conversion at BFP and subsequent results.

Camp Stool Ranch (CSR), which is owned and operated by the Mercer Family, is an operating cattle ranch. The field area planted to native grasses totaled 18.7 acres. The information on this ranch was obtained from interviews with Mike Mercer and Kristen Egen along with documentation from the NRCS. Several site visits were made to view the fields in the fall and spring. Dan Wolgast and Molly Hanson provided additional information concerning the grasses used and history of the site through interview questioning at the site.

Cobra Ranch (CR) is a Nature Conservancy property and part of the Aravaipa Canyon Preserve located at the headwaters of Aravaipa Creek, part of the Lower San Pedro Watershed. The initial native grass plantings encompassed 20 acres. Mark Haberstick, the preserve manager, provided excellent historical documentation of the efforts in restoring native grass to the major agricultural fields at the ranch. Table 2 presents information on the scope of reclamation effort at each site.

The key questions presented for each of the sites are listed in table 3. The people interviewed were able to provide information to answer the questions and are provided in the “Results” section. The information that was provided is of significant value with application to this study, the results and recommendations for further research.

Results

Q: What were the existing conditions prior to change from agricultural fields to native grass species?

A: The existing conditions for the three study locations varied from current agriculture crops, including cotton, Sudan grass, and wheat, to fallow for several years. BFP fields in the previous years were under a rotation of wheat and cotton. CSR had been growing Sudan grass and winter rye the prior season. CR fields were fallow the preceding 5 years with Sudan grass as the crop in the year 2002.

Table 1—Restoration sites, lower San Pedro watershed.

Site-Agency	Contact	Address	Phone and email
Black Farm Preserve	Ruth Valencia Senior Environmental Scientist	Mail Station PAB352 PO Box 52025 Phoenix, AZ 85072- 2025	(602) 236-2830 Ruth.Valencia@srpnet.com
Camp Stool Ranch	Mike and Lori Mercer Owners	Mike and Lori Mercer Box 157 Mammoth, AZ 85618	(520) 487-2021 mercerc2021@msn.com
Cobra Ranch Aravaipa Canyon Preserve	Mark Haberstick Preserve Manager	41099 W. Aravaipa Canyon Rd. Klondyke, AZ 85643	(928) 828-3443 mhaberstick@tnc.org
The Nature Conservancy	Molly Hanson Lower San Pedro River Program	1510 E. Fort Lowell Rd., Tucson, AZ 85710	(520) 357-6076 mhanson@tnc.org
The Nature Conservancy	Dan Wolgast Preserve Manager	80444 E. Pelayo Rd. Winkleman, AZ 85192	(520) 237-6064 dwolgast@tnc.org
The Nature Conservancy	Gita Bodner, PhD Conservation Ecologist	1510 E. Fort Lowell Rd., Tucson, AZ 85710	(520) 622-3861 gbodner@tnc.org
NRCS USDA	Kristen Egen District Conservationist	3241 N. Romero Rd. Tucson, AZ 85705	(520) 292-2999 Kristen.egen@az.usda.gov

Table 2—Scope of site reclamation.

	BFP	CSR	CR
Date of initial reclamation	2004	2008	2007
Approximate acreage initially involved	33	18.5	20
Approximate total acreage available for reclamation	101	18.5	50

Table 3—Analysis matrix.

	BFP	CSR	CR
1. What were the existing conditions prior to change over from agricultural fields to native grasses?	Rotation of wheat and cotton-prior season	Sudan grass and winter rye-prior season	Sudan grass-2002-fallow for 5 years prior to planting
2. What was the process used for preparing the fields?	Disc harrowed, furrowed, pre-irrigated	Disc harrowed	Disc harrowed leveled with field cultivator and dragged
3. Was soil weed seed load addressed prior to seeding?	Yes, pretreated with herbicides (pre or post emergent unknown)	No	Yes, irrigated to stimulate germination and then mowed once
4. What were the seeding techniques?	Mechanical broadcast	Drill seeder, hand broadcast	Drill, mechanical broadcast and hand broadcast
5. Was plugging used for Sacaton?	No	Yes	Yes
6. What was the seed mix used?	See detail listing	See detail listing	See detail listing
7. How successful was germination?	Varied with seed type, soil conditions, time of year applied and available water	Varied with seed type, soil conditions, time of year applied and available water	Varied with seed type, soil conditions, time of year applied and available water
8. What was the follow-up for watering and field maintenance?	Irrigation provided until server and transfer complete	Consistent application to maximize production	Sporadic to maintain cover and minimal growth
9. What is the current condition of the fields?	Weed populations with an abundance of native grasses	Abundant grasses that provide substantial forage and 62-1 ton bales of hay/17.8 acres	Native grass populations increasing providing hay
10. What are the water savings?	Total server and transfer	Approximate 50% reduction	Undocumented use, greater infiltration rate
11. Is grass-fed beef produced?	No	Yes	No

Q: What was the process used for preparing the fields?

A: All three sites used disc harrowing as part of the process used for preparing the fields for seeding native grasses. In addition, the first step in the process at BFP was to plow under the fields upon purchase of the property and then furrows were established for irrigation. CSR disced the field areas to be seeded. No other treatment accompanied the initial seeding. Later, wood chip mulch was added to try and improve the organic material content of the soils. CR disc harrowed, leveled, and dragged the fields. Seed drilling without disc harrowing was a follow-up method at CSR and seed drilling with imprinting was a follow-up method at CR. The addition of soil amendments including manure at

CSR and CR, wood chips at CSR, and beneficial mycorrhizal fungi at CR was a part of the preparation process for subsequent seed applications. The 2012 planting at CR will use a riphook and plow to prep the field. The theory behind this method is that it will disturb the gophers and allow the plants to grow enough to keep ahead of the gopher population and subsequent destruction of the plant root system.

Q: Was soil weed seed load addressed prior to seeding?

A: Soil seed load is one of the major problems inherent with the reclamation project, substantiated by literature review, and field interviews with the stakeholders. BFP pretreated with the use of herbicides

for broadleaf weeds prior to seeding. It is unknown at the time of writing the results if the pretreatment was a pre- or post-emergent herbicide. CR plowed, irrigated, and mowed prior to initial seeding of native grasses. The field at CSR had been under cultivation without an excessive weed seed load, and, therefore, the native grasses were seeded without treatment for a weed seed load prior to seeding. CSR and CR mowed to control weeds but did not use application of chemicals to control weed seeds. The three sites continue to use mowing as a method of weed control. Timely mowing is critical for success. The weeds must be allowed to mature to the point that flowers are forming or have formed, but seed has not yet set.

Q: What were the seeding techniques utilized?

A: The seeding techniques varied among the sites. BFP used a mechanical broadcaster initially but ran into problems with the seed clogging the equipment. The range drill proved to be the most effective for the majority of the seeding process. CSR and CR used a combination of drill seeder, mechanical broadcaster, and hand broadcasting. The native seeds vary in shape and size leading to difficulty with distribution mechanically by drill or broadcast. Close attention to the calibration and distribution of the seed is essential for good coverage and subsequent success of the crop. The range drill proved to be the preferred method of application with ease of use and successful distribution of seed for the larger seeds at all three sites. When the practitioners were questioned on the use of hydroseeding, they indicated that the process was too expensive to utilize although labor and project success were not factors in the expense calculations; only the initial rental cost of the equipment was considered.

Q: Was plugging used for Sacaton?

A: Plugging was not used at BFP but was used to establish Sacaton with later plantings at the CSR and CR sites.

Q: What was the native seed mix used?

A: The native seed mix varied with each site. NRCS used soil and historic vegetation analysis to help develop the seed list for each site. The actual seed mix varied due to the historic vegetation, soils, seed collection sources, available supply of seed from supplier, provenance of the seed source, and the individual budgets for seed purchase. BFP and CSR have similar soils (sandy bottoms) while CR soils have higher clay content. Granite Seed in Utah was the source for the BFP seed supply. Wildlands Restoration in Tucson, Arizona, supplied the seed for CSR and CR (refer to table 4 for listings of plant species).

Q: How successful was germination?

A: The results from the three sites indicate that germination success depends on a number of variables. The variables include, but are not limited to, the preexisting field conditions, field preparation, soil conditions, soil moisture content, natural rainfall, availability of supplemental water, time of year of seeding, methods of seeding, and provenance of seed and seed quality. The climatic conditions were similar for BFP and CSR as they are located west of the Galiuro Mountain Range within the Lower San Pedro River Valley several miles apart near Mammoth, Arizona. CR is in Aravaipa Canyon east of the Galiuro Mountain Range and experiences different climatic conditions. The average yearly rainfall for CSR and CR is 8 inches (http://www.clrsearch.com/Mammoth_Demographics/AZ/Weather-

Table 4—Native seed mix.

Black Farm Preserve (BFP)		
Botanical Name	Common Name	Application Rate
<i>Hilaria jamesii</i>	Galleta	0.8# per acre
<i>Setaria macrostachya</i>	Bristle Grass	1# per acre
<i>Sporobolus airoides</i>	Alkali-Sacaton	1# per acre
<i>Atriplex canescens</i>	Four Wing Salt-Bush	1# per acre
<i>Aristida</i> sps.	Three-Awn	.5# per acre
<i>Boutelous curtipendula</i>	Sideoats Grama	6# per acre
<i>Sporobolus crytandra</i>	Sand Drop Seed	unknown
Camp Stool Ranch (CSR)		
Botanical Name	Common Name	Application Rate
<i>Trichachne californica</i>	Arizona Cottontop	Mix @ 15# per acre
<i>Eragrostis intermedia</i>	Plains Lovegrass	
<i>Setaria macrostachya</i>	Large-spike bristlegrass	
<i>Bouteloua barbata</i>	Sixweeks Grama	
<i>Bouteloua curtipendula</i>	Sideoats Grama	
<i>Bouteloua gracilis</i>	Blue Grama	
<i>Botriochloa barbinodis</i>	Cane Bluestem	
<i>Leptochloa dubia</i>	Green Sprangletop	
<i>Setaria macrostachya</i>	Bristle Grass	
<i>Sporobolus wrightii</i>	Wright's Drop Seed	
Cobra Ranch (CR)		
Botanical Name	Common Name	Application Rate
<i>Andropogon barbinooides</i>	Cane Beardgrass	Mix @ 20# per acre
<i>Bouteloua gracilis</i>	Blue Grama	
<i>Bouteloua rothrockii</i>	Rothrock Grama	
<i>Festuca microstachys</i>	Small Flowered Fescue	
<i>Leptochloa dubia</i>	Green Sprangletop	
<i>Plantago insularis</i>	Indian Wheat	
<i>Schizachyrium scoparium</i>	Little Bluestem	
<i>Setaria macrostachys</i>	Plains Bristlegrass	
<i>Sporobolus crytandra</i>	Sand Drop Seed	

Forecast-Temperature-Precipitation?mammoth,az) while CR yearly rainfall average is 15 inches (USDI BLM 2010). Rainfall affects the ambient soil temperature and the soil moisture content, both of which influence seed germination. Although the three sites had variations with germination success it would appear that CR had inherently fewer challenges due to more favorable climatic conditions. The field conditions of BFP and CSR were similar in that they had been cultivated within the past year even though the crops at each site were different. CR had not been cultivated for a number of years and the soils were compacted and contained a substantial weed seed load. The soil at CR required tilling and irrigating for a season to reduce the weed seed load and create a more favorable seed bed. The seed source for BFP was Granite Seed in Utah. The seed supplied was harvested in Utah and, therefore, did not have the same genetic characteristics as the seed provided by Wildland Seed harvested in the Tucson area for CSR and CR. The genetic variation will have an effect on the long term success of the native grasses. This is evident with the necessity for BFP to reseed in subsequent years as a result of poor germination and seedling survival.

Q: What was the follow-up for watering and maintaining the fields?

A: BFP irrigated the fields for the first 3 years before sever and transfer of the water rights took place. The purpose for the conversion of the agricultural fields to native grasses at BFP was to transfer the water back to the river, the legal return of the water, and the water rights back to the river. The weed problem is a continuing issue and control with mowing on an as-needed basis is the method utilized. CSR provides irrigation on a regular basis with an established schedule. A center pivot system that provides water to the fields is turned on and off manually. Weed control is performed by mowing at the appropriate times to prevent seed formation. CR provides irrigation on an as-needed basis determined by soil moisture content and plant health. The fields were flood irrigated initially but recent installation of a wheel line system has allowed for changeover of some of the fields. Weed control was performed by mowing at the appropriate time and some hand weeding in select areas. The fields with native grasses will not need to be completely re-seeded in 3 to 5 years as do alfalfa fields or every year as with cotton.

Q: What is the current condition of the fields?

A: The BFP has weed populations with an abundance of native grasses although many species of native grasses are declining. CSR has weed populations with abundant grasses that provide substantial forage and hay. The native grass populations are increasing and competing with the weed population. Sixty-two 1-ton bales of native grass hay were harvested in the year 2010 from the 17.8 acres as opposed to the 45 bales of Sudan sorghum from the same area in previous years. The rancher indicates the cattle grazing on the native grasses are healthier, weigh more at the sale and produce better quality meat. CR has sporadic weed populations with native grass populations increasing providing hay for livestock and erosion control within the geographic area. Water infiltration of the soil has increased.

Q: What are the water savings?

A: Water savings at BFP were 100% as all the irrigation wells were turned off and the water allowed to flow to the river. The water savings at CSR is estimated at 50% calculated from the amount of time the pump runs compared to previous years with the high water-use crops on the fields. CR water use is not well documented. The water use on the fields to produce the previous crops was not recorded. A piezometer was installed in 2009 on the creek; prior to that no records of water use or impact on the river were maintained.

Q: Is grass-fed beef produced?

A: BFP and CR do not produce grass-fed beef for market. CSR is producing grass-fed beef and markets it at the local farmers market and other related outlets. The current market price for grass-fed beef is \$6.50 per pound (Cunningham 2012) as opposed to the price for grain finished or alfalfa-fed beef at \$3.87 per pound (Kavilanz 2012).

Conclusions

Analysis of field conditions prior to the onset of reclamation is critical to the approach taken for reclamation. Factors to be looked at and included in the plan are the type of soil, historic vegetation, weed seed load, existing or potential for irrigation, budget for the project and goal for the crop to be produced. The plan for reclamation can be formulated based on the previously mentioned factors and the goals for the project. Consulting with the NRCS will assist in the development of a comprehensive plan.

Careful attention to soil preparation, seeding methods, and continued care are essential for crop success. Documentation from Cobra Ranch indicates the areas with the highest success in establishing native grasses (i.e., germination and health of seedlings) were the sites in which weed seed load was reduced prior to planting, soils were prepared with nutrients, and additions were made as necessary. The method of seeding was based on the type of seed. Seeding occurred when appropriate seasonal parameters were met, supplemental irrigation was applied as needed, and weed control was performed as needed. Provenance of seed appears to have contributed to success. The seeded species appear to have established at higher frequency in fields planted with local seed compared with seed originating in Utah.

Camp Stool Ranch demonstrated that use of native grasses reduced water use (translated to energy use) and labor and the ongoing investment to maintain crops on the fields. The market for grass-fed beef is strong and supports the premise for developing native grass crops. The average retail price of ground beef is \$3.87 (Kavilanz 2011), while the market price for one pound of organic grass fed beef is \$6.50 (Cunningham 2012). CR has generated hay to use as mulch for restoration purposes or as feed for cattle that are foraging in large pastures where seed can be spread. The hay is valuable in more than dollars and cents as it provides a seed source that contains the gene pool indigenous to the area, an important factor for restoration projects. The neighbors are inquiring for hay for their livestock as well.

Analysis of the BFP fields indicates that it is possible to seed fields and provide irrigation for a limited time with some success in crop establishment. However, the long term success without supplemental irrigation is totally dependent on weather conditions and rainfall.

Each of the analyzed projects had different goals. The goal that SRP had for BFP was to establish native grasses and sever and transfer the water back to the river. The CSR goal is to establish a viable commercial agricultural crop. The crop in this case is grass-fed beef that they are now able to provide with the forage and hay produced by the native grass fields. The CR goal is to develop a seed bank, provide forage crops, and initiate a soil improvement program while working towards the ultimate goal of restoration of the giant sacaton habitat. Each of the goals for the separate projects has been demonstrated as being achievable. The key to success for the projects points to the attention to detail and following the prescribed plan.

The natural monsoonal patterns play a key role in the establishment of the grass crops. Additional irrigation is essential if the monsoon is not an active season delivering adequate rainfall. Long-term water needs for the crops will not be as great as the initial seeding and establishment period. Water must be available on a regular basis to have a successful germination and establishment of plants. Field

reclamation to native grasses is a viable option for an agricultural enterprise and holds multiple opportunities for the development of a sustainable agricultural environment ensuring resiliency to the changing climatic patterns through resource conservation. Resource conservation was demonstrated by the three sites with the reduction of water use and the reduction of extensive applications of fertilizers high in nitrogen required by alfalfa and cotton crops.

Recommendations

Recommendations are presented below for future research, analysis, and educational action.

1. Perform market-value studies for native grasses as forage, hay, seed banks, and restoration projects to substantiate the benefits of the native grass crop.
2. Develop the economic information to substantiate native grasses as a compelling agricultural crop.
3. Analyze the nutrient value of native grass hay compared to alfalfa to be used as a marketing and educational tool.
4. Determine per ton cost of native grass hay compared with alfalfa (yield analysis) to assist with education about native grass farming.

5. Educate the public about the importance of utilizing native grasses as a crop (figs. 1,2).

6. Extend a comparative analysis over a number of years by quantifying (1) labor for planting and care, (2) seed cost for the perennial crop versus annual or short-term crops, (3) fuel costs for preparing, planting, and field maintenance, and (4) nutrient and supplement needs (particularly nitrogen/urea application) of native grass versus other crops.


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Agricultural field restoration to native grasses will benefit the related communities with the reduction in use of ground water. The primary benefit for the environment will be the restoration of the water table with resulting increase flow in the river. Conversion of existing cotton and alfalfa fields to native grasses is a means to reduce labor, erosion, water use and weeds. The native grass crops may be used as forage, cover or harvested for hay for feed or seed banking.

Environmental and economic benefits for the local community and the entire system involved are significant. A concerted effort by all stakeholders to participate in the conservation of water, a finite natural resource, will ensure the future sustainability of the region. The natural ecosystem will benefit as well with the restoration of the related water table.


Conservation of natural resources is essential for future sustainability. Water table depletion and the resultant deterioration of the related ecosystems can be halted and reversed with good conservation practices including the utilization of drought tolerant native grasses as agricultural crops. Preliminary studies have shown an approximate 50% reduction in water usage with the utilization of native grass crops. Reduction of agricultural ground water use will result in natural restoration of the water table and the ensuing restoration of the riparian habitats associated with the river. Habitat restoration is essential for the continued health of the ecosystem as well as the communities along the river. The people are part of the landscape. Agriculture is part of the river.



AGRICULTURAL FIELD RESTORATION UTILIZING NATIVE GRASSES

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A GUIDE FOR THE
CONVERSION OF
TRADITIONAL AGRICULTURAL
CROPS TO NATIVE GRASSES

Figure 1—Sample brochure.

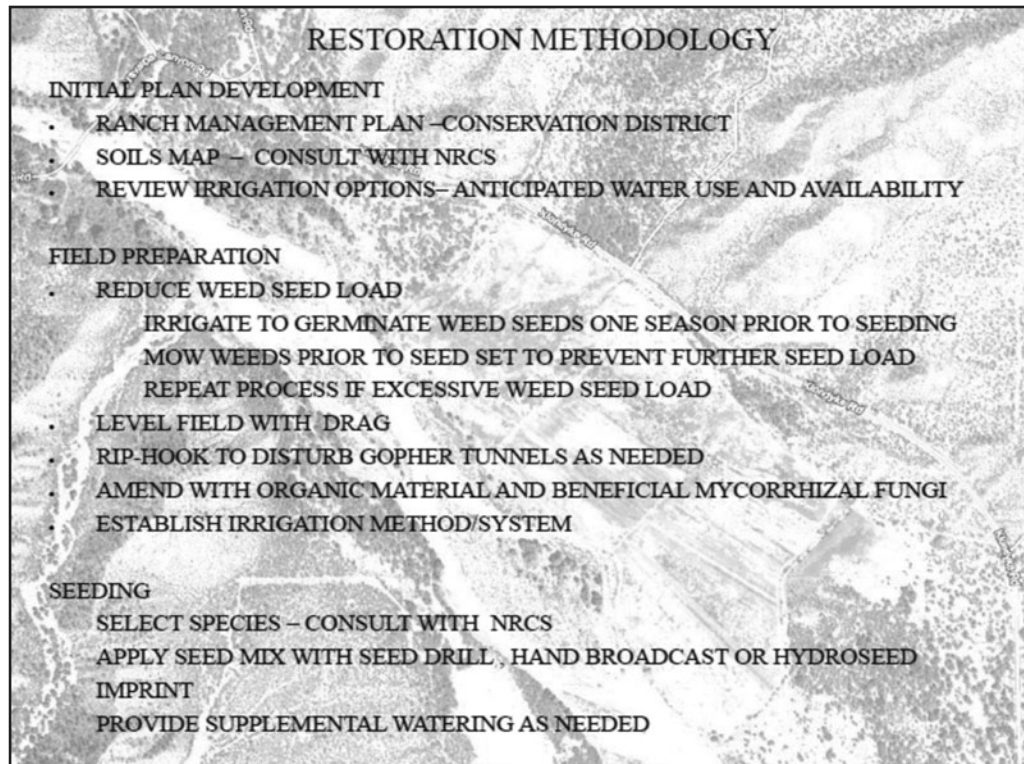


Figure 2—Sample restoration methodology.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Review of Black-Tailed Prairie Dog Reintroduction Strategies and Site Selection: Arizona Reintroduction

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Abstract—The black-tailed prairie dog (*Cynomys ludovicianus*) was once widely distributed throughout the western United States; however, anthropogenic influences have reduced the species' numbers to 2 percent of historical populations. Black-tailed prairie dogs are described as a keystone species in the grassland ecosystem, and provide many unique services, including burrows for other species (e.g. burrowing owls [*Athene cunicularia*] and rattlesnakes [*Crotalus* spp.]), nutrient rich soil that, in turn, provides rich vegetation for grazers, and food for many carnivores and birds of prey. Several efforts have been made to reestablish this species to its historical range. In southeastern Arizona, a recent reintroduction effort was built upon work of scientists that identified potential suitable areas with characteristics similar to those of existing prairie dog colonies in Mexico. Prairie dogs were first translocated to the sites in 2008, and individuals still remain on the landscape today. We compare this to other reestablishment efforts, and provide suggestions on ways to increase success of future reintroductions.

Introduction

Anthropogenic factors like land conversion and habitat destruction have become leading causes for decline in biodiversity worldwide (Wilson 1988), and have created a need for conservation or restoration of many species. One commonly used method of restoration is translocation. Translocation is the movement of living organisms from one area with free release in another (IUCN 1987), and can be used to establish, reestablish, or augment a population (Griffith and others 1989). A translocation is considered successful when the action results in a self-sustaining population (Griffith and others 1989). There are three classes of translocation: (1) Introduction: intentional or accidental movement of an organism outside its native range; (2) Re-introduction: the intentional movement of an organism into native range from which it has been extirpated by human activity or natural catastrophes; and (3) Re-stocking: movement of numbers of plants or animals of a species with the intention of building up the number of individuals of that species in an original habitat (IUCN 1987). For the purpose of this discussion, translocation will refer to the second category, re-introduction.

The black-tailed prairie dog (*Cynomys ludovicianus*; BTPD) is a burrowing rodent and is described as a keystone species in grassland ecosystems (Kotliar and others 1999, 2006; Miller and others 1994). This status suggests it provides a unique, significant service,

disproportionately to its abundance (Hoogland 2006), that no other species can provide. BTPDs provide burrows for other species (e.g. burrowing owls [*Athene cunicularia*] and rattlesnakes [*Crotalus* spp.]), excavate nutrient rich soil that produces rich vegetation for grazers (e.g. pronghorn [*Antilocapra americana*] and bison [*Bison bison*]), and serve as food for many terrestrial carnivores and birds of prey (Whicker and Detling 1988, Kotliar and others 1999, Underwood and Van Pelt 2000). BTPDs also maintain grassland ecosystems by preventing woody encroachment, contributing to landscape heterogeneity, and creating fire breaks through the short vegetation on their colonies (Kotliar and others 1999, Underwood and Van Pelt 2000). The loss of a keystone species can have profound effects on an ecosystem, including loss of biodiversity and community integrity (Kotliar and others 1999). For example, at least nine species rely on prairie dogs, and some populations decline as prairie dogs are eradicated (Kotliar and others 1999). Other species of prairie dogs including Gunnison's (*C. gunnisoni*: GUPD), white-tailed (*C. leucurus*: WTPD), Utah (*C. parvidens*: UTPD), and Mexican (*C. mexicanus*: MXPD) also may serve similar roles (Davidson and Lightfoot 2007, Miller and others 1994, Miller and others 2000).

The BTPD was once widely distributed in North America, but was widely viewed as a pest, and control programs put into place over the past century have reduced their numbers to 2 percent of historical populations (Whicker and Detling 1988, Miller and others 1994). By 1960, the species was extirpated from Arizona (Underwood and Van Pelt 2000), making Arizona the only state within their former range to completely eliminate the BTPD. In 1972 an effort to reintroduce the BTPD was made near Elgin, Arizona. It was unsuccessful due to disagreement between parties involved about release sites and methods (Brown and others 1974), and prairie dogs being released on the landscape without any site preparation (Brown, personal communication).

In 2003, after petitions to list the BTPD and WTPD were determined unwarranted by the U.S. Fish and Wildlife Service, a multi-state

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

plan was proposed to monitor and manage prairie dogs across their ranges (McDonald and others 2011). In 2008, to improve grassland health across the BTPD's historical range, Arizona Game and Fish Department (AGFD) implemented a plan to translocate BTPDs to Las Cienegas National Conservation Area (hereafter, Las Cienegas; fig. 1), in southeastern Arizona, which is located within the Madrean Archipelago. We will review the methods used for site selection and translocation of BTPDs to Las Cienegas, compare these methods to those used in other translocations, and provide suggestions to increase the likelihood of successful future translocations.

Site Selection

A 2005 study, conducted by the University of Arizona, compared characteristics of currently occupied BTPD colonies in Mexico with characteristics of potential translocation sites at Las Cienegas in southeastern Arizona. Researchers evaluated grass cover, forb cover, bare ground, visual obstruction, shrub density, tree density, gravel, sand, silt/clay, and grass species richness (Coates 2005). Las Cienegas was deemed a suitable site for translocation, and in 2008 the first colony was prepared by AGFD (see colony preparation below).

Other translocation efforts have only evaluated slope, type of soil, and type of vegetation on potential translocation sites (Long 2006) as well as visible and historical evidence of former prairie dog occupancy (Long 2006, Truett and others 2001). In areas being considered as translocation sites, woody plants, shrubs, and tall grasses may have encroached (Truett and others 2001) and modification to the environment must take place to prepare sites for translocation of BTPDs.

Colony Preparation

The best sites for translocation are those with vacant, intact burrows (Long and others 2006); however, many translocations do not have

access to intact burrow systems and must prepare overgrown sites for translocation. Methods of preparation include prescribed burns, mechanical shrub/woody plant removal, mowing, grazing, application of herbicides, seeding, and installation of artificial burrows (Truett and others 2001, U.S. Fish and Wildlife Service 2009).

Between 2008 and 2011, AGFD removed mesquite, mowed grass to <30 cm in height (the maximum height of vegetation preferred by BTPDs; Hoogland 1995), and installed 25 artificial burrows on each of four sites, 4 ha each, for translocation at Las Cienegas (fig. 2). A backhoe was used to install each artificial burrow that consists of one underground chamber, located 130-180 cm below ground accessible through a length of 10 cm diameter flexible tubing. Each burrow entrance was covered with an acclimation cage to deter initial dispersal (fig. 3), and four 20-25 cm deep starter burrows, one meter from the entrance of each artificial burrow, were dug around each artificial burrow entrance with an auger. Each colony site was located <5.6 km from another, within the dispersal range of BTPDs (up to 6 km; Hoogland 2006).

Methods of Capture and Group Composition

Arizona Game and Fish Department pre-baited 15 x 15 x 60 cm, double-door live traps (Tomahawk Live Trap Co., Wisconsin) and observed individuals at source populations, in New Mexico and Sonora, for 10 days prior to actual live-trapping. Observations serve to determine if the population is healthy (i.e., does not have plague), and to identify individual coterries, or family groups. After the initial 10 days, AGFD trapped BTPDs (of the *arizonensis* subspecies, which was historically found in Arizona), dusted for fleas, and translocated prairie dogs mostly together in observed coterries to increase success and reduce dispersal (Shier 2006a,b). A coterie is typically composed of one adult breeding male, three to four related breeding females, juveniles from the previous year, and yearlings (Hoogland 1995). AGFD translocated a minimum of 60 prairie dogs to three new colonies at Las Cienegas, and will translocate individuals to the fourth colony in October 2012.

In other translocation efforts with recipient sites in New Mexico and South Dakota, mixed family groups (randomly mixed prairie dogs from the same colony) had similar survival to same family groups, and workers discontinued transporting animals in family groups because "it was easier and more economical" (Long and others 2006). However, a study of the same prairie dog colony in New Mexico indicated that individuals translocated in family groups had higher reproduction and were five times more likely to survive post translocation than prairie dogs that were not translocated in family groups (Shier 2006a). The discrepancies in these two studies can be explained by the methods of evaluating survivorship, and the size of translocated family groups. Long and others (2006) estimated survivorship through visual counts of prairie dogs 2 months after translocation, whereas Shier estimated survivorship by live trapping all individuals and offspring 1 year after translocation (Shier 2006b). Also, same-family groups translocated to South Dakota were only partial family groups (average of five individuals per group) whereas "same-family" groups translocated to New Mexico were complete family groups (average of 11.3 individuals per group; Shier 2006b). This suggests that, wherever possible, family groups should be determined prior to capture and transport, and prairie dogs should be translocated as family groups to increase the chance of success.



Figure 1—Approximate location of Las Cienegas National Conservation Area, Arizona, indicated by star.

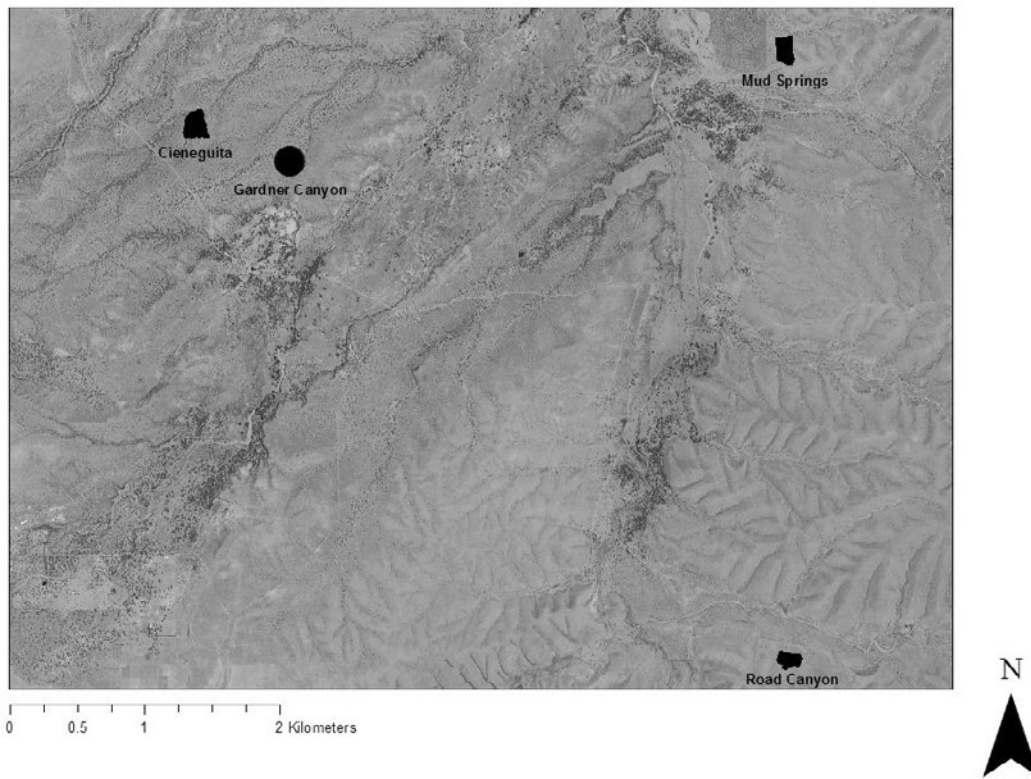


Figure 2—Colony locations at Las Cienegas National Conservation Area (Cieneguita, Road Canyon, Mud Springs) have received black-tailed prairie dogs (*Cynomys ludovicianus*). Gardner Canyon has been prepared but has not yet received prairie dogs.

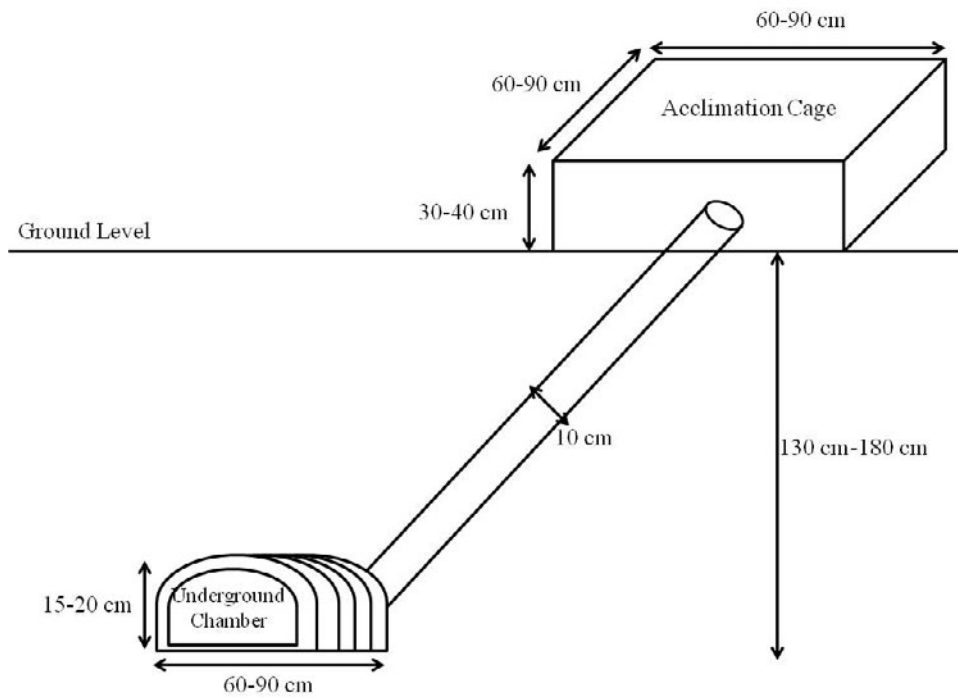


Figure 3—Artificial burrow consisting of an underground half-cylinder nest chamber connected to surface by 10-cm diameter flexible plastic tubing. Acclimation cage is placed above the burrow entrance to dampen dispersal and provide refuge from predators. Modified from Long et al. 2006.

Acclimation Cages

Hard release is the process of capturing, transporting, and releasing animals in a new location without any acclimation period (Clark and others 2002, Franzreb 2004). Soft release is the same process of animal capture and transport to a new location, but allows animals to acclimate to their new location for a period of days or weeks before release (Franzreb 2004).

Using the soft release method, AGFD installed wire acclimation cages over burrow entrances to dampen dispersal and provide refuge from predators (fig. 3). Prairie dogs were provided with food (Purina herbivore chow, Phoenix Zoo), carrots, and water *ad libitum* while the acclimation cages were in place to restore energy lost during transport, burrow excavation, and stress from being in a new environment (U.S. Fish and Wildlife Service 2009). Acclimation cages were left in place for 2 weeks; however, almost all prairie dogs excavated a tunnel out of the cages before their removal (Sarah Hale, personal observation of black-tailed prairie dogs at Las Cienegas, October 2011).

Prairie dogs not kept in acclimation cages have a higher probability of dispersal. During dispersal, prairie dogs are more vulnerable to predators, and therefore have high mortality rates (Hoogland 1995, 2006). One group of prairie dogs had 100 percent dispersal from starter burrows when acclimation cages were not used (Truett and others 2001). Another study found that, after acclimation cages were used

for 5 to 15 days, most animals continued to use starter burrows for up to 1 year during which time they excavated new burrows nearby (Truett and others 2001). These findings suggest that the use of acclimation cages increases the success of translocations by reducing dispersal immediately following translocation.

Environmental Stochasticity

Las Cienegas National Conservation Area is located at the southwestern periphery of the BTPD's former range (fig. 4). This arid system is much harsher than more northerly locations, and may cause prairie dogs translocated to these systems to have poor survival and reproduction compared to prairie dogs in more temperate parts of their range (Facka and others 2010). Between May and June 2011, one BTPD population at Las Cienegas decreased by 54 percent, and only produced one juvenile that subsequently died, but at least 9 females showed signs of parturition (Hale, unpublished data). We speculate that this was due to lower than average rainfall that created a lack of available food resources. Furthermore, we speculate that lack of resources caused increased infanticide, and the need to forage farther away from the safety of burrows, making prairie dogs more vulnerable to predation; we documented three fatalities caused by predators on colony peripheries where tall vegetation obscured nearby predators (two coyotes [*Canis latrans*]; one red-tailed hawk [*Buteo jamaicensis*]).



Figure 4—Historical range of the black-tailed prairie dog (*Cynomys ludovicianus*; modified from Hall 1981). Approximate locations of source populations in New Mexico and Mexico are black circles. Approximate location of Las Cienegas National Conservation Area in Arizona is black square.

Our findings are consistent with another study that observed prairie dogs foraging on colony peripheries when resources were scarce, and found they were more vulnerable to predation (Koford 1958) than those foraging in colony centers. Drought led to the collapse and local extirpation of several BTPD populations translocated to the Chihuahuan desert (Facka and others 2010). This suggests that drought years can greatly hinder translocations of BTPDs to their former range in arid regions.

After the precipitous population decline at one of the Las Cienegas colonies, AGFD began supplemental feeding starting in June 2011. The same feed provided to individuals in acclimation cages was placed at or near burrow entrances in an attempt to keep prairie dogs closer to burrows. No additional predation events were observed after supplemental feeding began, and only two more individuals disappeared from the colony between June and October while the supplemental feed was available (Hale, unpublished data). In 2012, supplemental feeding began in March to increase survival and reproduction, and at least 70 juveniles were observed at the same colony that produced only one the previous year (Holly Hicks, Sarah Hale, personal observation of black-tailed prairie dogs at Las Cienegas, April 2012). With the apparent massive improvement to recruitment, supplemental feeding will likely continue to be provided from March-July during dry years until the colony appears to be resilient in drought periods.

Population Augmentation

A translocation is considered successful when a population becomes self-sustaining (Griffith and others 1989). The three occupied colonies at Las Cienegas have not yet become self-sustaining (table 1), but, due to the drought and the unique nature of this translocation effort, it is too early to draw a conclusion. Because the three Las Cienegas populations are not yet self-sustaining, populations have been augmented yearly, usually in September or October, with new individuals, to increase numbers and genetic diversity, from the same source populations from which the new colonies are started (MacDonald Ranch, NM, Ladder Ranch, NM, Sonora, Mexico). Augmentation has also been recommended for populations of UTPDs when a significant decrease in the spring count is observed (U.S. Fish and Wildlife Service 2009) and was necessary for sustaining translocated populations of Gunnison's prairie dogs in Sevillita National Wildlife Refuge in New Mexico (Friggens and others 2009). Augmentation is not used in all translocations, but may prove to be a valuable tool in arid climates until populations can withstand drought and predation.

Table 1—Population abundances for black-tailed prairie dogs (*Cynomys ludovicianus*) at each colony on Las Cienegas between 2008 and 2012. X indicates colony not yet in existence. Post-Augmentation indicates population size after new individuals were added to an existing colony. Population abundances prior to October 2011 are based on visual estimates, whereas after September/October 2011 all individuals were trapped and counted.

	Oct 2009		Oct 2010		Sept/Oct 2011		April 2012	
	Oct 2008	Pre-augmentation	Post-augmentation	Pre-augmentation	Post-augmentation	Pre-augmentation		Post-augmentation
Road Canyon	74 ^a	18	57	18	43	10	40	≥23 ^b
Mud Springs	X	68 ^a	n/a	17	46	12	42	≥25 ^b
Cienegueta	X	X	X	64 ^a	n/a	20	40	99

^aColony received prairie dogs for the first time at this date.

^bSpring count not completed at this date for these colonies.

Conclusions

Arizona Game and Fish Department has returned a native species to the state after a 50-year absence. With the help of the University of Arizona, they were able to evaluate potential translocation sites in more detail than other translocation efforts. Reliable methods of site preparation and artificial burrow installation have been used; methods of capture, group composition and acclimation, as well as continued augmentation have all increased the likelihood of success of populations translocated to Las Cienegas.

The arid climate of Las Cienegas will continue to provide challenges in reestablishing the BTPD. Drought and predation have led to lower survival and reproduction than expected, but supplemental feeding at Las Cienegas seems to keep prairie dogs closer to their burrows, reduces risk of predation, and increases recruitment greatly. Continued supplemental feeding during drought periods will be crucial to permit the BTPD to become self-sustaining once again in the state. Future translocations in Arizona, and other arid regions, should consider the effects of drought, and provide supplemental food before population declines occur in these sensitive populations. In the long term, seeding sites and management for desired grass composition may be a tool to replace supplemental feeding. Augmentation may also be a useful method for increasing success of translocations, particularly in arid climates.

Acknowledgments

We thank Bill Van Pelt and Tim Snow for their early efforts in bringing the black-tailed prairie dog back to Arizona.

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Trajectory and Rate of Desert Vegetation Response Following Cattle Removal

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Abstract—Cattle have grazed continuously over the past three centuries in the Sky Island region and most work has focused on how these grazers have affected riparian and grassland habitats. I examined the effects of grazing on a fuller spectrum of desert habitats that occur in the close proximity to the San Bernardino Valley of Mexico and the United States. Plots in each of five habitats were placed in two adjoining areas: where grazing had not occurred for 25+ years and where grazing had only ceased 4+ years before this study. Vegetation responded quickly to removal of cattle in mesic environments and formed a species-poor, structurally diverse community. Grazing in more xeric communities did not affect vegetation cover but increased plant species richness. The differences in grazed and ungrazed areas of xeric habitats may indicate these areas were little affected by grazing or that the response after grazing ends is slower than captured by the time course represented here. Exotic species were essentially limited to recently grazed areas of the riparian habitat.

Introduction

Vegetation changed dramatically during the late 1800s over large areas of the warm North American deserts, including the “Sky Islands” (sensu Warshall 1994), after a prolonged drought, coupled with large-scale cattle grazing period, followed by a period of unusually high precipitation (Bryan 1925; Hastings and Turner 1965). Rivers and streams that had coursed through uncut channels (1) incised the landscape lowering water levels and (2) changed rivers and streams from sources of perennial surface water to dry channels with flow present only after sufficient rains (Bryan 1928; Cooke and Reeves 1975). Valleys that had been grasslands were replaced by shrubs and subtrees (Bahre 1991; Bull 1999; Hastings 1959; Humphrey 1987). The contribution of cattle grazing to the change in vegetation over this period has been debated (Hastings and Turner 1965). Grazing had been widespread and stocking rates often high over much of the region since Spanish explorers first arrived in the 1600s (Wagoner 1952, 1960). However, the scant written description of this period leaves it difficult to interpret what early effect the large cattle herds had on vegetation. A lack of information on the early grazing impacts coupled with observations that dramatic vegetation changes occurred in the late-1800s in places cattle had never been suggests there is little support that grazing alone was the cause of abrupt vegetation change in the late-1800s. Some combination of climatic and human-caused factors likely coincided to bring about this change in vegetation (Hasting and Turner 1965). Empirical results from the present-day will provide further insights into this discussion.

Because of their importance to ranching and agriculture, the riparian and grassland habitats have received most attention regarding the effects of cattle grazing on vegetation communities (Stromberg and Tellman 2009, and references therein). However, these habitats cover a minority of the area in the present-day sky island region. Fewer studies have addressed how grazing affects desert scrub and other more xeric habitats that cover the largest expanse of North American warm deserts.

This study examined differences and rates of change of plant species richness, cover and composition after cattle grazing ended in five desert plant communities of the Chihuahuan desertscrub biome (Brown 1994). In addition to habitat, grazing histories also differed on adjoining areas; in one area cattle had been removed in 1979 after it had been purchased as habitat for endangered species (the present-day San Bernardino National Wildlife Refuge, Department of the Interior), and the other area had been ranched until 2000 when cattle were removed and agriculture was stopped (the present day Rancho San Bernardino, Fundación Cuenca de los Ojos). The difference in history of land use allowed me to compare floras at sites that had experienced recent cattle activity to floras at nearby sites that had no cattle present for 25+ years. Plant sampling sites were in five highly interdigitated habitat types in a small area (approximately 16 km²). Close proximity of sites meant the same plant species could have potentially occurred in each habitat and differences in plant species richness and abundance due to rainfall, temperature, and other climatological conditions were minimized. Sampling designs such as these has been called “space for time comparisons” and are informative not only about how communities respond to disturbance but also the rate and extent of succession after disturbance (Fukami and Wardle 2009). Specifically, I asked the following three questions: (1) do plant species richness and cover increase in habitats with greater water availability and is this pattern the same where recent grazing has occurred as where it has not? (2) does the rate of vegetation change correspond to water availability? and (3) how does water availability influence distribution and species richness of non-native species?

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Methods

The study was done in the San Bernardino Valley, which runs north-south across the Mexico-United States border in northeastern Sonora, Mexico, and southeastern Arizona, USA. Elevation is approximately 1070 m and climate is xeric temperate with an annual average precipitation of 360 mm. Description of the climate and area are detailed in Minckley (2008).

In fall 2003, eight sites were established in each of five habitat types; desert scrub, mesquite scrub along minor (upland) drainages, mesquite forest along major drainages, grassland, and riparian. The same sites were sampled again in spring 2004. These habitats are not discrete but do reflect a soil moisture gradient from highly saturated in the riparian zone along a permanent stream to more xeric in upland vegetation associations (creosote bush scrub, mesquite grassland, and mesquite forest) where cacti and desert shrubs occur such as *Acacia constricta* (whitethorn acacia), *Larrea tridentata* (creosote bush), and *Flourensia cernua* (tarbush). Grasses were common, but not dominant, in most of the grassland and were absent from the other upland vegetation types. Mesquite (*Prosopis juliflora*) occurred in both the grassland and mesquite forest, and creosote bush was the dominant perennial in the creosote bush scrub. For brevity, hereafter I refer to these vegetation types as follows; desert scrub, grassland, and riparian as written but mesquite scrub along minor (upland) drainages as bosque dry, and mesquite forest along major drainages as bosque wet.

In each habitat, half (4 of 8) of the sampled sites were located on ranchlands in Mexico that had been taken out of grazing 3 years before this study began. Cattle on this ranch had been stocked year-round when the cattle operation was active, and in the 2 years before cattle were removed (1999-2000), stocking density was approximately twice as high as recommended for long-term forage sustainability (J. Austin, pers. comm.). This area is referred to hereafter as the grazed area. The other sites in the United States had not experienced grazing since 1979 and are referred to hereafter as in the ungrazed area.

Vegetation was sampled using a multi-scaled sampling method developed and described by Stohlgren and colleagues (Barnett and Stohlgren 2003; Stohlgren et al. 1998). These plots are 20 m x 50 m and subdivided into two non-overlapping 10 m² and one 100 m² subplots. This size and rectangular shape of the plots provides a better estimate of vegetation heterogeneity in landscapes than smaller Daubenmire and Parker transects that have been traditionally used by field ecologists (Muller-Dombois and Ellenberg 1974). Stohlgren et al. (1998) found that approximately 45-80% more plant species and a greater proportion of rare, habitat specialist species are sampled in these plots than in the smaller plots. Where plots were located was determined using random numbers. Once the plot origin was fixed, the long axis of the plot was oriented to maximize number of species a plot included.

In each plot, the species composition, species frequency (= abundance) and cover of plants was measured. Plots were measured in all five vegetation types in the grazed and ungrazed areas for a total of 40 plots (4 plots x 5 habitats x 2 grazing histories). Each plant species was categorized as native or exotic based on information available through the United States Department of Agriculture (plants.usda.gov, accessed on 15 April 2012) and a species list for Sonora, Mexico (T. Van Devender, unpubl. data).

I first tested with a t-test if the plant species richness recorded in plots differed among the spring and fall samples. Secondly, I tested with a 2-way ANOVA for the effect of grazing on species richness by treating habitat and grazing history as main effects with species density as the variable. Third, I tested with a 2-way ANOVA for the effect of grazing on percentage cover by plants by treating habitat and grazing history as main effects with percentage cover as the variable.

To gauge the level of heterogeneity among plots, habitats and grazing histories, I compared all habitat and grazing history combinations using Jaccard's similarity index.

Results

There were 147 plant taxa recorded from the plots, of which 133 were identified to species and 14 were considered uncertain identifications. This latter group was not included in the species number and cover estimates. There were more species in the spring than in the fall when calculated as total species (spring = 105 species; fall = 89 species), or if calculated as average species richness per habitat (fig. 1: spring = 18.7 ± 1.06 s.e., fall = 12.4 ± 1.06 s.e.; $p < 0.0001$). Only the riparian habitat did not have more plant species in the spring than in the fall sample. The seasonal difference in species number was particularly pronounced in the driest three habitats, desert scrub, bosque dry, and grassland (fig. 1). In all of the analyses, we tested both spring and fall data however, I limit the discussion to the spring data because there were no differences in the results among seasons and there were more species observed.

A complete list of the species will be available in the journal *Checklist* (www.checklist.org.br/) and made available as a Research Species list in Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org).

Species Richness and Cover

Grazed habitats had significantly more plant species (mean = 21.75 ± 1.1 s.e.) than ungrazed habitats (mean = 15.65 ± 1.1 s.e.; t-test, $p = 0.0005$) and there were more species where grazing had occurred recently than where cattle had not been present for approximately 23+ years, in all but the bosque dry habitat (fig. 2). Tukey's test of all pairwise comparisons showed there were significantly more species in grazed areas of desert scrub, grassland, and riparian habitats than in ungrazed areas of more mesic riparian and bosque wet habitats.

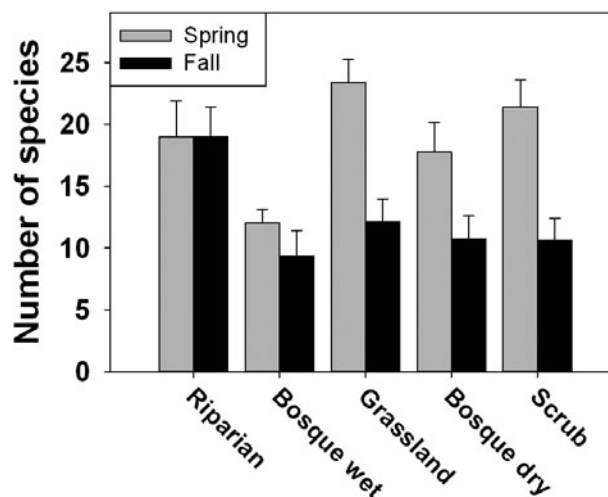


Figure 1—Seasonal differences in average number of plant species recorded from eight plots per habitat in five habitats. Each plot was sampled twice, once in spring 2004 and again in fall 2003. Significantly more species were recorded in the spring.

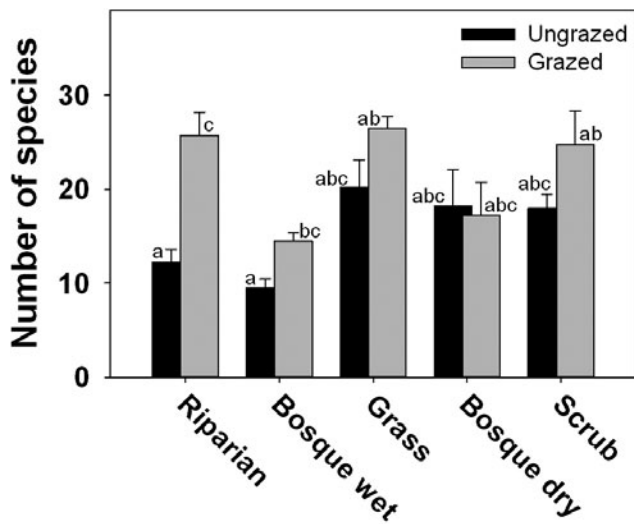


Figure 2—Mean plant species from plots in five habitats that had either experienced grazing ca. 5 years before this study or had not been grazed for 25+ years before the study. More plant species occurred in most habitats in the areas where cattle had been grazing recently. Letters above columns indicate significant differences.

However, in most habitats there was no significant difference in plant species richness when grazed and ungrazed areas were compared except for the riparian habitat where there were significantly fewer plant species in the ungrazed area than in the grazed area (fig. 2).

Mean percent cover did not change in response to grazing history. Post-hoc Tukey’s test revealed only one comparison differed significantly; plots in ungrazed areas of grassland had less cover than in plots of the ungrazed area of the riparian habitat (fig. 3). Cover was

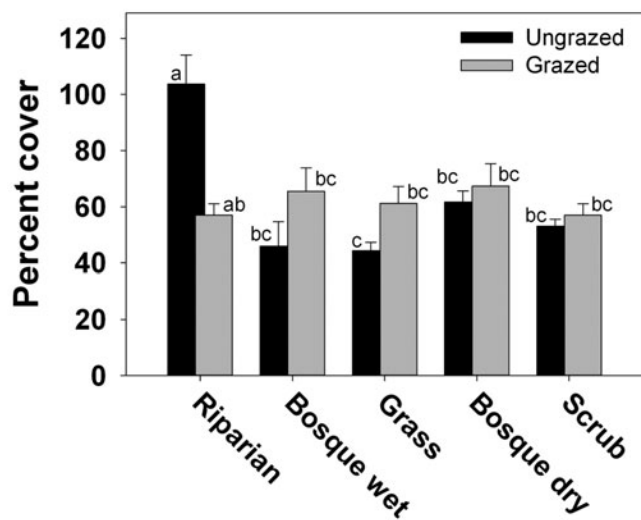


Figure 3—Mean plant cover from plots in five habitats that had either experienced recent grazing or had not been grazed for 25+ years. Cover in most habitats was similar in grazed and ungrazed areas except for the riparian zone. Letters above columns indicate significant differences.

not significantly different in any habitat when plots in grazed and ungrazed areas were compared.

Species Similarity

Vegetation composition varied considerably among habitats, most notably in the riparian habitat where cottonwood dominated the area that was ungrazed, but had not become established downstream in the 3 years after grazing had ended (figs. 4, 5). Approximately 30% of the vegetation coverage in habitats was by four perennial plant species (fig. 4), two that occurred in all habitats (mesquite and sacaton bunchgrass, *Sacaton wrightii*), one that occurred in all habitats except riparian (creosote bush), and one limited to the riparian habitat (cottonwood, *Populus fremonti*). Plant composition among plots was very heterogeneous, as is best exemplified by the low mean species similarities of the samples taken at different plots within the same habitat and grazing history (mean = 37.9%, range from 0.28 bosque wet grazed – 0.49 desert scrub ungrazed).

Exotic Species

There were six introduced species found in the plots; although only the widespread mustard, *Eruca vescaria*, occurred in desert scrub and

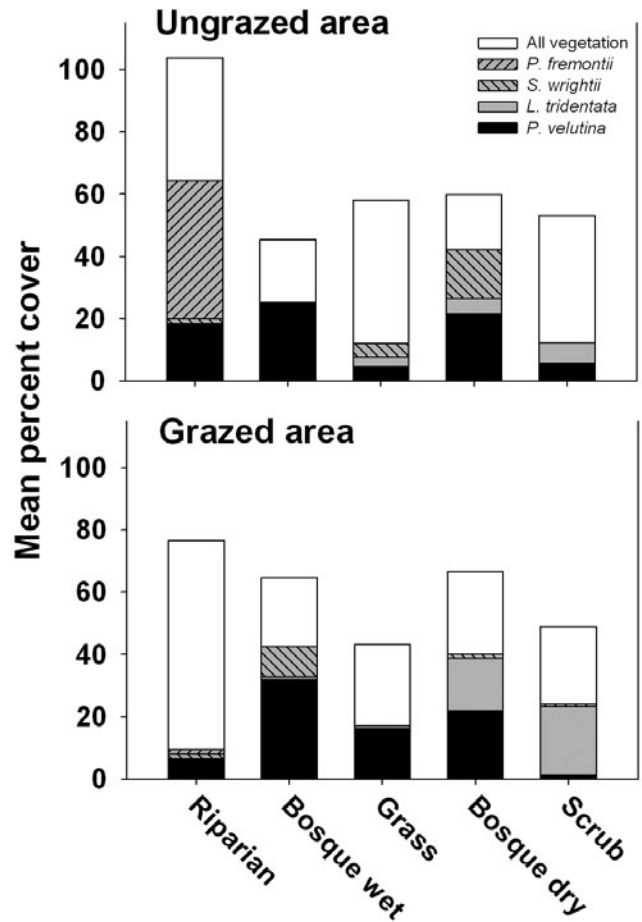


Figure 4—Differences in average cover of all vegetation, and of four perennial species in plots of five habitats that had either not been grazed by cattle for 25+ years or had experienced recent grazing.



Figure 5—The rapid response of riparian vegetation after the San Bernardino National Wildlife Refuge was established is evident from these photographs from 1979 (left) and 2002 (right) of the Rio San Bernardino (= Black Draw) at the United States-Mexico border. The longer and narrower white arrows in both images indicate north, and the heavy short arrow in the left hand image indicates the approximate source and direction that the image on the right was taken. The United States-Mexico border is distinct in the right hand photo by the continuous line extending from the top to the bottom of the aerial photograph and is less distinct in the left hand photos where it runs from the left to right and traverses the river at the last *Populus fremontii* on the Rio San Bernardino (=Black Draw). The aerial photograph from 1979 shows an unvegetated, exposed riverbed on both sides of the border with few *P. fremontii*. Along the river in the left photo is found an almost continuous forest that has grown since 1979 and is yet to establish along the river in Mexico, where grazing occurred until 3 years before the photo.

bosque dry habitats and only tumbleweed, *Salsola tragus*, occurred in the grassland habitat (table 1). All exotic species occurred in the grazed riparian habitat, but only two of these species occurred in the riparian habitat that was ungrazed. The amount of cover represented by exotic species was less than 5% in all habitats except the riparian habitat with the lowest coverage in the desert scrub habitat. Coverage of introduced species in the riparian habitat was 7-fold greater in the grazed area (25.4%) than in the ungrazed area (3.4%).

Discussion

Despite considerable differences in vegetation among plots within habitats, in the five habitats, and in the 23+ year difference in grazing history, the pattern of vegetation response showed water availability affected how the community composition changed and how quickly such changes occurred. The difference was most marked in the riparian habitat where a cottonwood-dominated gallery forest is now

Table 1—Distribution and identity of exotic species in spring, 2004. Four plots were sampled per habitat and grazing history type. Percent cover is the average for each exotic species in the four plots and percent cover of exotics is the percentage cover by exotic species of all vegetation (not percentage of entire plot). The greatest species richness and overall cover of exotic species occurred in the riparian ungrazed habitat. Exotic species were rare or absent in drier habitats.

Habitat, grazing history	Plant species	Num. plots (of 4 max)	% Cover	% Vegetation cover by exotics
Bosque dry, grazed	—	—	—	—
Bosque dry, ungrazed	<i>Eruca vescaria</i>	2	0.1	0.2
Bosque wet, grazed	<i>Eruca vescaria</i>	1	0.1	
	<i>Cynodon dactylon</i>	1	0.5	0.9
Bosque wet, ungrazed	<i>Eruca vescaria</i>	2	0.3	
	<i>Cynodon dactylon</i>	1	0.2	
	<i>Salsola tragus</i>	2	0.2	1.5
Grass, grazed	<i>Salsola tragus</i>	1	0.2	0.5
Grass, ungrazed	—	—	—	—
Riparian, grazed	<i>Eruca vescaria</i>	2	0.3	
	<i>Cynodon dactylon</i>	4	11.8	
	<i>Melilotus indicus</i>	3	2.6	
	<i>Salsola tragus</i>	2	0.6	
	<i>Sorghum halepense</i>	1	4.1	
	<i>Tamarix ramosissima</i>	1	0.03	25.4
Riparian, ungrazed	<i>Cynodon dactylon</i>	2	1.5	
	<i>Sorghum halepense</i>	4	2.0	3.4
Scrub, grazed	<i>Eruca vescaria</i>	2	0.3	0.6
Scrub, ungrazed	<i>Eruca vescaria</i>	1	0.4	0.8

present where cattle had been removed in 1979 (fig. 5). Although in this habitat the cover was the greatest of any habitat sampled (fig. 3), species richness was the lowest (fig. 2). Xeric shrub and grassland habitats in the San Bernardino Valley are high in species number, and rivaled only by grazed riparian habitat where cottonwood forest had not become established. Shrub and grassland habitats in grazed and ungrazed areas differed much less in the species found there (fig. 2) and the percent cover (fig. 3) than was observed in the riparian habitat, indicating low water availability does not limit species richness but slows the rate vegetation responds once grazing is reduced.

In this study area, grazing depressed recruitment of cottonwoods in the riparian habitats resulting in eventual extirpation of the species where permanent water was present. Cottonwoods present today were largely absent in this area when cattle grazing was first discontinued in 1979 (fig. 5). The absence of a cottonwood canopy in the grazed riparian area enabled numerous shrubs and annual species to colonize and persist there, many of which were found otherwise in xeric habitats. Both the lack of sunlight and excess soil moisture exclude some plant species from riparian habitats where continuous forest canopy occurs. Upon cessation of grazing in riparian habitats, cottonwoods and other fast growing mesic-adapted plants become established and eventually displace other, lower-growing, species.

In comparison to riparian habitat, the effect of grazing on desert scrub and grassland habitats is more difficult to interpret because it is not possible to disentangle if (1) grazing had little effect on these habitats, or (2) if grazing had a large effect and the rate vegetation responded in these habitats was slower. Though rarely considered, the first hypothesis is not implausible given grazing density and duration for more distant habitats is reduced because cattle remain within a few kilometers of sources for water, especially when air temperatures are high. In the San Bernardino Valley, grassland, desert scrub, and bosque dry habitats are often further from permanent water than riparian and bosque wet habitats. Stock tanks in the grazed area hold water ephemerally today (author, personal observation) and probably behaved the same in the past. Therefore, the more xeric habitats may have experienced lower grazing intensity than riparian and bosque wet habitats. If grazing did have little effect on desert scrub and grassland communities in the San Bernardino Valley, these data suggest that grazing results in greater plant species richness and little change in composition.

Alternately, if grazing had a strong effect of vegetation in desert scrub and grassland, this study is consistent with the conclusion that after grazing ends the species richness declines gradually, and the response by vegetation is slow. The 25-year span of vegetation change represented in this study is not long enough to distinguish which hypothesis (or others) is most reasonable. Further monitoring of the sites studied here and others is needed.

Exotic species were most diverse and represented the greatest coverage where soil moisture was greatest and sunlight was not impeded by a cottonwood canopy (riparian, grazed habitat). The lack of exotic species in xeric habitats is consistent with observations of other studies (Tellman 2002). Furthermore, there are clear management implications of this pattern given that the habitats where exotic species are concentrated are the most localized of any habitat in the region; management to repress the establishment and spread of exotic species may be sometimes feasible even if resources are limited.

Although only eight plots were sampled per habitat in this study, and half of these were in areas that had been recently grazed or not grazed for 25+ years, the comparisons suggest grazing influences vegetation in most, if not all, habitats and these effects may be positive or negative. Where surface water occurs, vegetation responds rapidly to reduced grazing and generates a distinctive low-diversity community

dominated by trees. These same habitats are grazed most intensively when cattle have access to them, which results in greater species richness and changes in vegetation composition that approached those observed in adjacent xeric habitats. In xeric habitats, such as desert scrub, the long-term effects are more difficult to establish based on data in this study. It is possible these habitats are little changed other than the increased species richness related to physical disturbance of soils and better penetration or improved emergence by seeds. If they did change substantially when grazed, the rate of recovery appears slow. Either way, the differences in vegetation among habitats here illustrate the complexity managers of biodiversity are confronted with; is grazing maintained to promote local biodiversity or should grazing be discontinued and fewer species maintained locally?

Although cattle removal leads generally toward lower plant species richness, particularly in the mesic habitats, cattle removal has a disproportionate effect in the functional diversity of the whole ecosystem (Petchey and Gaston 2002; Svenson and Enquist 2009). Habitats with great vertical development (gallery forests of cottonwoods) not previously found, or barely present in the grazed area, add ecological complexity to the natural setting. In the mesic sites with low specific diversity, the capture of carbon in thick tree trunks is greatly increased, and the litterfall and carbon addition to soils and watercourses is increased manifold. These factors, mainly associated to increased functional diversity might increase the overall ecosystem functioning and the beta and gamma diversity.

Finally, although this study was done in 1 year, the patterns match those recorded during a vegetation survey in 2000 (Minckley and Burquez, unpublished report), the year after cattle were first removed from the grazed area of this study. This matching pattern supports the conclusion that the effects reported in this study are still related to grazing despite a 3-year lag after grazing ended in the ungrazed area and a 25+-year lag after grazing ended in the ungrazed area.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Fire

Soil Erosion and Deposition Before and After Fire in Oak Savannas

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***Abstract**—Effects of low severity prescribed burning treatments and a wildfire on soil erosion and deposition in the oak savannas in the Southwestern Borderlands are reported. Measurements in the spring and fall, respectively, characterize soil movements following winter rains and high-intensity summer rainstorms. Annual values are also presented. Relationships between soil erosion and deposition and precipitation amounts, physiographic characteristics, and vegetation were analyzed to determine possible cause-and-effect implications. The information should be useful in developing strategies for re-introducing more natural fire regimes into the oak savannas.*

Introduction

Low severity wildfires were common in the Southwest Borderlands before Euro-American settlement. However, the severities and frequencies of the fires in the region have been altered since the early 1900s largely because of fire suppression policies of management agencies and livestock grazing at this time removed significant portions of the fire-carrying herbaceous fuels (Fulé and Covington 1995). These practices and policies have resulted in increased densities of tree overstories on many sites making them more susceptible to wildfires, insects, and diseases. Unwanted woody plants have often invaded productive rangelands. As a consequence of these conditions, management agencies and their collaborators are exploring the possibility of re-introducing a “more natural” fire regime into the ecosystems of the region including the oak savannas situated between the higher-elevation and more dense oak woodlands and lower-elevation grassland-shrub communities.

Estimates of average soil erosion and deposition before and after cool- and warm-season prescribed burning treatments and a wildfire in the oak savannas are the focus of this paper. Preliminary estimates have been reported earlier (Ffolliott and others 2005). The information presented in this paper and the earlier publication should be useful

in accessing the possible effects of re-introducing a more natural fire regime on soil movement in the oak savannas of the Southwestern Borderlands region.

Cascabel Watersheds

Twelve watersheds, ranging from 20 to almost 60 ac in size, located in the Peloncillo Mountains of southwestern New Mexico were the study site. The total area of these watersheds, called the Cascabel Watersheds, is 451.3 ac. They are situated between 5,380 and 5,590 ft in elevation. The nearest long-term precipitation station indicates that annual precipitation averages 21.8 ± 1.2 in., with nearly one-half falling in summer rainstorms. Streamflow originating on the watersheds is intermittent. High flows can be generated by high-intensity summer rainstorms (Gottfried and others 2006). Most of the surface soils are very gravelly or very cobbly sandy loams or sandy clay loams (Robertson and others 2002). Additional vegetative, geologic, physiologic, and hydrologic characteristics of the watersheds are described elsewhere (Ffolliott and others 2008, Neary and Gottfried 2004, Youberg and Ferguson 2001, and others) and, therefore, are not presented.

Prescribed Fire Treatments and Wildfire

The original objective of the research program on the Cascabel Watersheds was to compare the effects of cool-season (November through April) and warm-season (May through October) prescribed burning treatments on ecosystem resources and hydrologic functioning of the watersheds with similar evaluations on unburned watersheds to assess the impacts of the burning treatments. Following the calibration

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period, four of the watersheds were burned during the cool-season in early March 2008. Three of the four watersheds to be burned in the warm-season were burned on May 20, 2008, with burning of the fourth watershed scheduled for a later date. However, wind gusts of up to 60 mph blew burning embers onto the remaining watershed to be burned and the four control watersheds in the morning of May 21, 2008. The resulting Whitmire Wildfire crossed the watershed boundaries and spread out to burn nearly 4,000 ac. The current research program, therefore, is evaluating the effects of the prescribed burning treatments and the wildfire on the features originally sampled, including soil erosion and deposition.

Fire Severities

A system relating fire severity to the soil-resource response to burning (Hungerford 1996) was used to classify the severities of the prescribed burning treatments and wildfire on the watersheds. Classifications at the sample plots on the watersheds (see below) were then extrapolated to a watershed-basis to determine the proportion of the watersheds that were unburned or had burned at low, moderate, and high severities. It was determined that all of the watersheds had burned at low severities (Stropki and others 2009).

Study Protocols

Sampling Basis

Between 35 and 45 sample plots that had been established along transects perpendicular to the main stream systems on each of the Cascabel Watersheds were the basis for obtaining the measurements of soil erosion and deposition. Intervals between these plots varied depending on the size and configuration of the watershed. A total of 421 plots were located on the 12 watersheds. These plots have also been used in other studies of ecosystem resources on the watersheds (Gottfried and others 2007).

Measurements of Soil Erosion and Deposition

Three capped pins were placed around every third plot on the watersheds to measure soil erosion and deposition. Measurements of soil loss beneath a cap (soil erosion) or soil accumulation above a cap (deposition) were made in the spring and fall to characterize soil movements following periods of winter rains and summer rainstorms, respectively. Occasionally, there was no change in the soil surface beneath the cap in which case either the magnitudes of soil erosion and deposition between the successive measurements equaled each other or (what is less likely) neither erosion nor deposition occurred. The capped pins were re-set to be flush with the soil surface after each measurement to facilitate subsequent measurements. Measurements obtained at a plot were averaged to estimate soil movements at the plot and the plot measurements on a watershed were then averaged to describe soil erosion and deposition on a watershed-basis. A bulk density value of 70.5 lbs/ft³ was used to convert the measurements of soil erosion and deposition to corresponding measures in tons per acre on a watershed-basis.

Initial measurements were made in the fall of 2004 with pre-fire measurements continuing in the spring and fall until the burning events occurred. Post-fire measurements were initiated in the spring of 2008 shortly following the cool-season burns with these measurements then made in the fall of 2008 and the spring and fall of 2009 and 2010.

Analysis

Measurements of soil erosion and deposition were analyzed separately because they are separate processes of soil movement. Results of the Shapiro-Wilk test of normality indicated that the frequency distributions for soil erosion and deposition were non-normal. Transformations failed to normalize the distributions. Therefore, occurrences of statistical differences in the measurements were determined by the non-parametric Mann-Whitney test of significance (Zar 1999). This test was applied because the estimates of the respective processes were independent of each other. Plots with no measurable change in soil movement were excluded from the analyses. Differences were evaluated at the 0.10 level of significance.

Results and Discussion

Measurements of soil erosion and deposition are summarized by bar graphs (see below) showing the magnitudes of the respective processes before and after the burning events. Inferences relating to differences in the magnitudes of the two processes are not necessarily valid, however, because the frequency distributions of the data used in developing the bar graphs were non-normal. Significant differences in the measurements of soil erosion and deposition were determined through interpretations of the Mann-Whitney test.

Pre-Fire

There were no statistically significant differences in either soil erosion or deposition among the individual watersheds throughout the pre-fire period. Therefore, the respective data sets were pooled for analysis.

Soil erosion—Soil erosion measurements obtained in the spring following the winter rains were compared to the fall measurements after the summer rainstorms to determine whether seasonal or annual differences occurred. Spring measurements were statistically similar to the fall measurements with an average of 14.6 t/ac. Annual soil erosion averaged 14.2 t/ac. Differences in soil erosion within the seasons and years of measurement were insignificant.

Soil deposition—Soil deposition after the winter rains was also compared to the measurements taken following the summer rainstorms to determine if seasonal differences occurred before the burning events. It was found that the deposition of soil in the spring differed from the depositions in the fall, 4.6 and 7.8 t/ac, respectively, with annual soil deposition averaging 6.3 t/ac. Differences in soil deposition within the seasons and years of measurement were inconsistent and, therefore, considered insignificant.

There were no consistent relationships in the magnitudes of soil erosion or deposition and rainfall patterns or the physiographic characteristics or vegetation surrounding the sample plots.

Post-Fire

Comparisons of the post-fire data sets indicated that there were no significant differences in soil erosion or depositions on the respective watersheds experiencing the prescribed burning treatments or wildfire. Therefore, the data sets were pooled for comparison with pre-fire values.

Soil erosion—Soil erosion following the prescribed burning treatments and wildfire was greater (19.1 t/ac) than measurements of pre-fire soil erosion following winter rains but lower after the

summer rainstorms (10.5 t/ac) in relation to pre-fire measurements (fig. 1). There was no significant difference in annual soil erosion as a consequence of the burning events. The seasonal measurements of soil erosion appeared to “balance” each other on an annual basis.

That the annual post-fire erosion of soil after the burning events was within the range of the pre-fire value was likely a result of similar erosive forces generated by rain drops impacting on the soil surface throughout the pre- and post-fire periods. Furthermore, the absence of widespread water repellent soils after the burns (Stropki and others 2009), and, as a consequence, the likelihood of a little change in the overland flows of water necessary to dislodge soil particles from a site occurred. There also was little evidence of increased rill formations on the hillslopes of the watersheds following the three burning events.

Soil deposition—Post-fire deposition of soil following the winter rains was statistically similar to the pre-fire deposition (fig. 2). However, the deposition measured after high-intensity summer rainfalls was significantly greater (11.7 t/ac) following the burning events for a reason unknown to the authors. Soil deposition on an annual basis was also greater following the burning events (9.4 t/ac) because of the difference in the fall measurements.

Similar to the pre-fire findings, soil erosion and deposition following the prescribed burning treatments and wildfire were not related to the rainfall events, physiographic characteristics, or vegetation.

Summary

The information presented in this and the earlier paper on soil movement on the Cascabel Watersheds (Ffolliott and others 2005) should be useful to people interested in knowing the effects of re-introducing a more natural fire regime into the oak savannas of the Southwestern Borderlands. However, knowledge of the effects of prescribed burning treatments of higher fire severities, in other seasons, and on the array of ecosystem resources and factors affecting the hydrologic functioning of watersheds in the oak savannas is necessary before attempting to introduce more natural fire regimes through prescribed burning treatments.

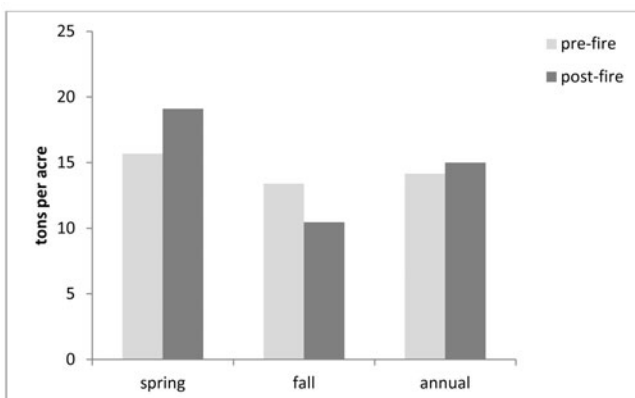


Figure 1—Seasonal and annual soil erosion on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Averages for the respective study periods are shown in the figure.

Acknowledgments

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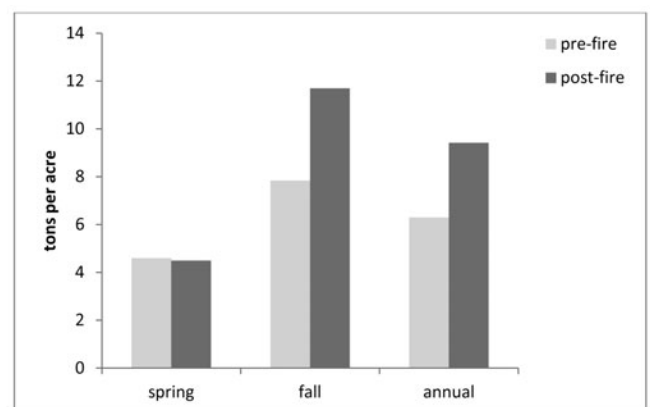


Figure 2—Seasonal and annual deposition of soil on the Cascabel Watersheds before and after the prescribed burning treatments and wildfire. Averages for the respective study periods are presented in the figure.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Hillslope Treatment Effectiveness Monitoring on Horseshoe 2 and Monument Fires

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Abstract—Between February and July, 2011, over 360,000 acres burned across the Coronado National Forest during one of the most active fire seasons in recorded history. Burned Area Emergency Response (BAER) Teams evaluated post-fire watershed conditions and prescribed treatments based on threats to known values at risk. Hillslope stabilization treatments were prescribed and implemented for areas of high soil burn severity on both the Horseshoe 2 and Monument Fires. These treatments consisted of seeding on the Horseshoe 2 Fire and application of agricultural straw mulch and seed on the Monument Fire. Initial monitoring results indicated one of three seeded species (*Hordeum vulgare*) emerged in both burned areas, slightly improving effective ground cover in both treatments. However, seeding treatments failed to meet monitoring success criteria for the Horseshoe 2 and Monument Fires. Hillslope erosion was reduced where mulch treatment was applied correctly and where slope gradients were moderate on the Monument Fire, and appeared to contribute to seeded species cover. In the Horseshoe 2 Fire, hillslope erosion was high on the treatments transects and was not reduced by seeding alone. A need for additional monitoring in spring 2012 exists and would improve the current understanding of the effectiveness of hillslope treatments.

Introduction

The summer of 2011 saw record wildfires across the southwestern United States. In southeastern Arizona, the Horseshoe 2 Fire burned approximately 222,954 acres in the Chiricahua Mountains (<http://inciweb.org/incident/2225/>), and the Monument Fire burned approximately 30,526 acres in the Huachuca Mountains (www.inciweb.org/incident/2324/) (fig. 1). Both fires burned watersheds that drain onto developed private lands and rural ranches. In Arizona, monsoon rains immediately follow wildfire season and are often how fires are ultimately extinguished. The quick, intense burst of rainfall from relatively common (<2-5 yr frequency) storms can generate large floods and debris flows in watersheds disturbed by wildfires. U.S. Forest Service (USFS) Burned Area Emergency Response (BAER) assessments were completed for both fires. Soil burn severity maps show 12% of the Horseshoe 2 Fire burned at high severity and 30% at moderate severity, while 7% of the Monument Fire burned at high severity and 39% at moderate severity. Moderate to high soil burn

severity in both fires occurred on moderate to very steep slopes in the upper watersheds. The BAER teams conducted hydrologic analyses of post-burn conditions using a 5-year return-interval storm with an intensity of $1/2$ inch/hour. Results indicated an estimated increase of post-fire peak flows from 2-15 times in the Horseshoe 2 burned area (USDA 2011a), and from 3-10 times in the Monument burned area (USDA 2011b).

To mitigate predicted increases in post-fire runoff and consequential risks posed to life, property, and soil productivity within and near the burned areas, hillslope treatments were prescribed for selected areas of moderate and high soil burn severity on USFS-managed lands. Aerial seeding was applied to treatment areas in the Horseshoe 2 burned area from July 16 through July 18 and in the Monument Fire on July 29. Seed mixtures included *Hordeum vulgare* (annual barley), *Bouteloua gracilis* (blue grama) and *Pascopyrum smithii* (western wheatgrass) for the Horseshoe 2 Fire, and *H. vulgare*, *B. gracilis* and *Elymus trachycaulus* (slender wheatgrass) for the Monument Fire. The seeding was applied, with variable seed coverage, by fixed-wing aircraft. Agricultural straw mulch was applied over seeded units in the Monument Fire from August 2 to 17, 2011; no agricultural straw was used to stabilize hillslopes in the Horseshoe 2 Fire.

The objective of this study was to evaluate the initial effectiveness of hillslope treatments within both burned areas. To evaluate if treatments were successful or not within the first year of application, the study plots were monitored to determine if (1) seeded species germinated and became established, (2) seeded species provide effective cover for soil stabilization, (3) straw mulch cover was uniform throughout Monument Fire treatment units, (4) straw mulch treatment

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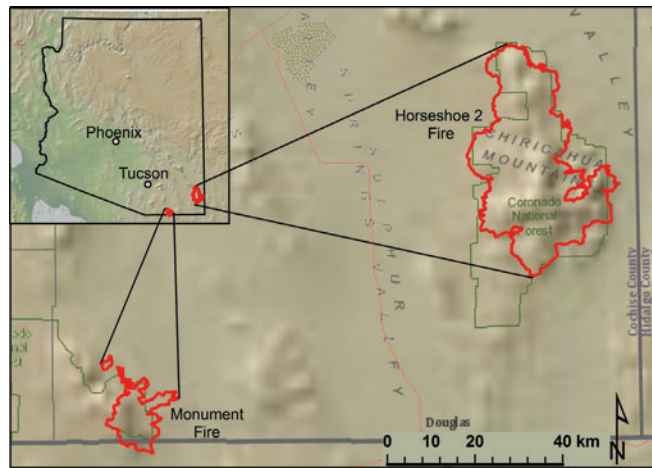


Figure 1—Location of Horseshoe 2 Fire and Monument Fire in south-eastern Arizona.

successfully reduced soil erosion in the Monument Fire, and (5) wind was a factor in moving the straw mulch in the Monument Fire.

Methods

Site Selection

Burned areas suitable for seeding and mulching treatments had moderate to high soil and vegetation burn severity with slope gradients between 40 and 60%. Appropriate areas for treatment were identified by the BAER teams (USDA 2011a,b,c). Within the treatment areas, preliminary transect locations were selected on the basis of soil burn severity (USDA 2011a,b) vegetation burn severity (USDA 2011c), aspect (table 1), and accessibility. Potential treatment and control transect locations were located in the field based on ArcGIS-derived UTM coordinates. Transects were established in areas that represented average hillslope conditions while avoiding natural drainages which may have contributed to pre-fire hillslope erosion that would not have been mitigated by treatments. The number and location of control transects were limited as most of the potential treatment areas were seeded (Horseshoe 2) or seeded and mulched (Monument).

Data Collection and Analysis

Two rain gauges were installed on the Monument Fire and one was installed in the study area of the Horseshoe 2 Fire (northern half of the fire) in early July with a second gauge installed in late July. Rain fell on both fires before any of the hillslope treatments could be applied. The first significant rains fell on the Monument Fire on July 10 (table 2) and on the Horseshoe 2 Fire on July 11 (table 3). Both storms produced debris flows and floods. The NOAA Atlas 14 classifies both storms as a 2-year/30-minute frequency. During July and August, 10 storms on the Monument Fire (table 2) and 11 storms on the Horseshoe 2 Fire (table 3) produced enough runoff to generate either debris flows or floods with peak discharges sufficiently large to threaten or cause damage to values at risk based on reports from BAER team implementation teams and local residents.

Thirty-meter transects were established along contour to collect rill network density and effective ground cover data (fig. 2). For each transect, the width and depth of each rill was measured for the first

10 m, distance between rills was measured within the first 15 m, and total number of rills was tallied for the entire length. Average values for distance between rills and rill width and depth measurements for each fire were calculated to compare treatments with control sections. Rill cross-sectional areas, ranges, averages, and standard deviations were calculated by treatment for each fire.

Effective ground cover (EGC) data collected from 1 m square quadrats included native vegetative cover, seeded species cover and count, large woody debris, and litter (Brady and Weil 2000; DeBano and others 1998; Pannkuk and Robichaud 2003). Agricultural straw cover and clumps of agricultural straw within 1 m of treatment transects were also measured in the Monument Fire. Square meter quadrats were read every 3 meters for the length of each transect. Cover frequency index (CFI) was calculated for each EGC variable for treatment and control transects sampled in each burned area. This metric combines frequency of occurrence and absolute percent cover for each variable analyzed (Benkobi and Uresk 1996; USDA 2006). Ground cover was determined to be effective at reducing erosion when all variables measured contributed to 70% or greater cover (Pannkuk and Robichaud 2003; Robichaud 2005). Successful treatment implementation and germination of seeded species included the presence of all three seeded species, an average of greater than 20 seeded individuals in treatment quadrats, and a CFI of twice the overall vegetation CFI for treatment transects (Johnson 2004).

Data were collected from September 22 through 27, 2011. Six treatment and three control transects were established in the Horseshoe 2 burn area and seven treatment and two control transects were established in the Monument burned area (table 1). One potential treatment transect in the Monument Fire was abandoned due to safety concerns.

Results

Rill Density

Measurements were collected along transects to obtain rill density and cross-sectional areas, although not all transects intersected rills. On the Horseshoe 2 Fire, rill measurements were collected on four of six of the treated transects and two of three of the control transects (tables 4 and 5, fig. 3). One control transect intersected a single rill beyond 15 m; therefore, no measurements were collected. On average, there were a greater number of rills in the treatment transects, and rill cross-sectional areas were 64% lower for treatment transects than for control transects.

On the Monument Fire, rill measurements were collected on four of seven treated transects and two of two control transects (tables 6 and 7, fig. 4). One treated transect intersected three rills beyond 15 meters; therefore, no measurements were collected for this transect. On average, there were a greater number of rills in the control transects. However, rill cross-sectional areas were 37% lower for treatment transects than for control transects.

Effective Ground Cover

H. vulgare was the only seeded species observed during data collection. This grass species was present in 71% of Horseshoe 2 treatment quadrats, accounting for an average of 10.7% cover and 7.6 CFI (table 8), and in all Monument treatment quadrats, accounting for an average of 7.8% cover and 7.6 CFI (table 9). *H. vulgare* cover on the Horseshoe 2 Fire was highest where soil and vegetation burn severity was moderate and lowest where soil and vegetation burn

Table 1—Transect locations, soil burn severity, vegetation burn severity, aspect and transect sample type. (c = control, untreated)

Fire	Transect	Burn Severity		Aspect ^c	Sample Type
		Soil ^a	Vegetation ^b		
Monument	1	moderate	high	east	treatment
	2	moderate	high	east	treatment
	3	moderate	high	north	treatment
	4	high	high	east	treatment
	5	high	high	north	treatment
	6c	moderate	high	north	control
	7c	high	high	east	control
	8	moderate	high	east	treatment
	10	high	high	north	treatment
	Horseshoe 2	11	high	high	north
12		high	moderate	south	treatment
13c		high	high	south	control
14		moderate	moderate	west	treatment
15c		moderate	moderate	west	control
16		mixed	mixed	west	treatment
17		mixed	mixed	south	treatment
18		high	high	north	treatment
19c		high	high	north	control

^aSoil burn severity derived from BAER Assessment Team’s Final Soil Burn Severity GIS (USDA 2011a & b).

^bVegetation burn severity downloaded from USFS Remote Sensing Application Center, Salt Lake City, 09/17/2011.

^cAspect generated from 30 meter DEM in ArcMap 9.3.1 with Spatial Analyst (ESRI 2011).

Table 2—Significant rainfall events from two ALERT gauges within the Monument Fire burned area. Dates of hillslope treatments are shown in right column.

Miller Canyon ALERT Gauge				Ash Canyon ALERT Gauge			Treatments
Date	Storm Total (mm)	Storm Duration (h:mm:ss)	Average Storm Intensity (mm/hr)	Storm Total (in)	Storm Duration (h:mm:ss)	Average Storm Intensity (mm/hr)	
10-Jul	41.66	1:04:00	39.1				
20-Jul	29.46	1:17:16	22.9	6.1	2:14:48	2.7	
23-Jul	9.14	0:12:00	45.7	10.2	0:14:17	42.7	
26-Jul	8.13	0:35:32	13.7				
28-Jul	19.30	5:04:57	3.8	31.5	4:08:01	7.6	
29-Jul	2.03	0:42:31	2.9	11.2	1:20:20	8.3	Seeding Applied
31-Jul	12.19	4:43:42	2.6	31.5	4:01:28	7.8	
11-Aug	3.05	0:44:49	4.1	8.1	1:08:45	7.1	Straw Mulch Applied Aug 2-17
13-Aug	6.10	3:00:32	2.0	13.2	1:39:21	8.0	
20-Aug	22.35	1:00:07	22.3	17.3	0:21:18	48.7	
22-Aug	2.03	0:12:10	10.0	15.2	0:24:24	37.5	
23-Aug	9.14	0:11:22	48.3				

Table 3—Significant rainfall events from two gauges within the Horseshoe 2 Fire burned area. Dates of hillslope treatments are shown in right column.

UA/B2 Chiri Gauge & NWS KC2CPZ1 Weather Station				
Date	Storm Total (mm)	Storm Duration (h:mm:ss)	Average Storm Intensity (mm/hr)	Treatments
11-Jul	54.4	1:38:31	33.1	
12-Jul	8.6	0:35:52	14.4	Seeding Applied
26-Jul	13.0	0:32:45	23.7	July 16-18
28-Jul	7.9	0:59:29	7.9	
3-Aug	6.4	0:13:17	28.9	
9-Aug	6.0	0:11:35	31.1	
11-Aug	24.6	2:40:59	9.2	
13-Aug	18.0	1:25:56	12.6	
15-Aug	24.6	0:51:04	28.9	
24-Aug	10.9	0:47:38	0.54	

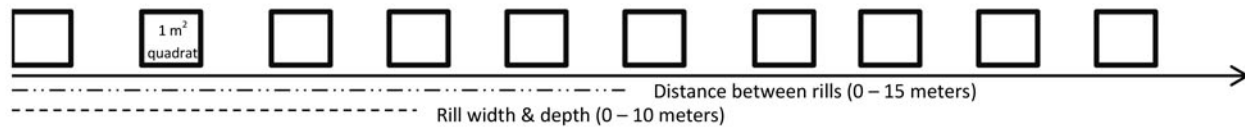


Figure 2—Transect sample design. Total number of rills were recorded for the length of transects and effective ground cover variables measured from quadrats.

Table 4— Distance between rills for the Horseshoe 2 Fire.

Transect	Number of rills (0.00- 15.0 m)	Distance between rills (m)	
		Range	Average
Treatment	14	0.1 to 3.85	0.83
	0	NA	NA
	0	NA	NA
	5	0.12 to 1.55	0.57
	7	0.5 to 5.75	2.00
Control	18	0.08 to 2.05	0.52
	0	NA	NA
	3	0.15 to 6.3	2.29
	0	NA	NA

Table 5— Rill density and cross-sectional area measurements for the Horseshoe 2 Fire.

Transect	Number of rills (0.00- 10 m)	Rill width (m)		Rill depth (m)	
		Range	Average	Range	Average
Treatment	9	0.15 to 0.7	0.31	0.005 to 0.04	0.02
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	5	0.07 to 0.12	0.10	0.005 to 0.03	0.02
	4	0.05 to 0.02	0.12	0.02 to 0.03	0.02
Control	11	0.09 to 0.6	0.28	0.005 to 0.06	0.02
	0	NA	NA	NA	NA
	3	0.3 to 1.3	0.67	0.03	0.03
	0	NA	NA	NA	NA

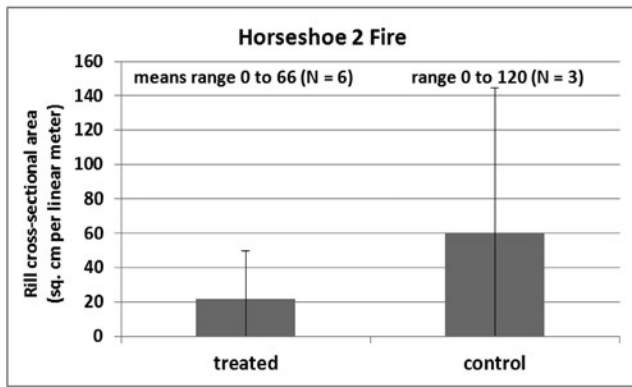


Figure 3—Horseshoe 2 average rill cross-sectional area with error bars for treatment and control samples.

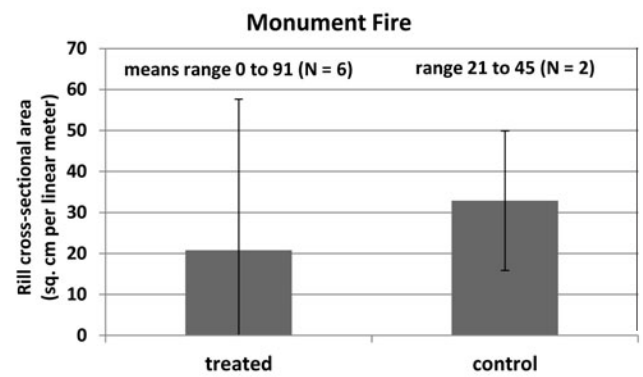


Figure 4—Monument Fire average rill cross-sectional area with error bars for treatment and control samples.

Table 6—Distance between rills for the Monument Fire.

Transect	Number of rills 0- 15 m	Distance between rills (m)	
		Range	Average
Treatment	15	0.04 - 6.3	0.68
	0	NA	NA
	0	NA	NA
	22	0.04 - 2.92	0.55
	0	28.35	NA
	0	NA	NA
	0	NA	NA
Control	19	0.09 - 2.95	0.69
	12	0.06 - 2.5	0.83

Table 7—Rill density and cross-sectional area measurements for the Monument Fire.

Transect	Number of rills 0- 10 m	Rill width (m)		Rill depth (m)	
		Range	Average	Range	Average
Treatment	11	0.08 - 0.48	0.26	0.015 - 0.06	0.03
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	8	0.05 - 0.39	0.2025	0.005 - 0.035	0.013
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
	0	NA	NA	NA	NA
Control	11	0.07 - 0.24	0.13	0.0025 - 0.03	0.01
	10	0.11 - 0.65	0.32	0.005 - 0.03	0.019

severity was high. The highest and lowest *H. vulgare* cover on the Monument Fire were recorded where soil burn severity was moderate and vegetation burn severity was high. Four treatment transects on the Horseshoe 2 Fire and one treatment transect on the Monument Fire had an average of less than 20 individuals per quadrat. Average percent cover was less than 20% on all treatment transects.

Other vegetative cover was comprised primarily of native species. No invasive species were observed during data collection. The CFI of other vegetation was 10.0 for treatment and 4.8 for control transects on the Horseshoe 2 Fire and 6.3 for treatment and 2.5 for control transects on the Monument Fire. Non-vegetation effective ground cover was comprised of litter and rock with the addition of straw on the Monument Fire. Total non-vegetation effective ground cover CFI was 22.8 for all treatment transects combined and 11.5 for all control transects combined (table 9). The total number of straw clumps within 1 m of a treatment transect ranged from zero to eight on four of seven transects, indicating poor treatment application on some of the treatment areas. Non-vegetative ground cover for both fires had higher CFI for treatment and controls than overall vegetation CFI.

Seeding Success Criteria Evaluation

Treatments failed to meet success criteria for seed treatment application for both fires (table 10). Success criteria were based on monitoring methods of the Nuttall Complex on the Coronado National Forest (Johnson 2004) and Santiago Fire on the Cleveland National Forest (Wohlgenuth and others 2010).

Discussion

Both the Horseshoe 2 and Monument Fire burn areas experienced significant precipitation prior to hillslope treatment implementation. Following treatment implementation, the treated areas were exposed to numerous other storms. These precipitation events varied in intensity and location, and contributed to hillslope erosion before and after treatment implementation.

After initial data collection in September of 2011, 33% of seeded species (mostly *H. vulgare*) had established in treatment units in both burned areas. Although *Bouteloua gracilis* (blue grama) and *Pascopyrum smithii* (western wheatgrass) were absent from treatment transects, these species may yet emerge following 2011-2012 winter

Table 8—Horseshoe 2 Fire effective ground cover variables cover frequency index by sample type.

EFG variable		Treatment	Control	Treatment	Control
Seeded species (treatment)	<i>Hordeum vulgare</i>	7.62	NA	21.64	4.85
	<i>Bouteloua gracilis</i>	0	NA		
	<i>Pascopyrum smithii</i>	0	NA		
Other vegetation		10.02	4.85	40.58	50.75
Litter		4.85	27.14		
Rock		32.49	23.26		

Table 9—Monument Fire effective ground cover variables cover frequency index by sample type.

EFG variable		Treatment	Control	Treatment	Control
Seeded species (treatment)	<i>Hordeum vulgare</i>	7.59	NA	6.46	2.54
	<i>Bouteloua gracilis</i>	0	NA		
	<i>Elymus trachycaulus</i>	0	NA		
Other vegetation		6.26	2.54	22.78	11.54
Straw		36.39	NA		
Litter		2.96	1.15		
Rock		32.34	50.35		

Table 10—Seeding treatment success matrix.

Fire	Success criteria	Treatment transects meeting criteria (%)
Horseshoe 2	Average of 20 seeded individuals in quadrats	33
	Seeded species CFI twice the overall vegetation CFI	33
	Germination of all seeded species	0
Monument	20 seeded individuals in treatment quadrats	86
	Seeded species CFI of twice the overall vegetation CFI	42
	Germination of all seeded species	0

rains. Germination of seeded species was somewhat successful as only two of three seeded species were observed. Seeding slightly improved EGC on hillslope treatment units on both fires where seeds remained onsite following exposure to rainfall and slopes were moderate (closer to 40%). Overall treatment CFI was higher than controls and was attributed to both seeded and non-seeded species cover. Lack of consistently high emergence or high CFI of seeded species across treatment transects was attributed to seed mobilization during rainstorm events as high *H. vulgare* cover was observed on roads and in riparian areas downslope and downstream from treatment units in both burned areas (C. Gibson, personal observation). Agricultural straw mulch over seeding treatment on the Monument fire is assumed to have contributed to the higher average number of

H. vulgare individuals because of higher number of individuals and more even distribution than observed in the Horseshoe 2 treatment quadrats (C. Gibson, personal observation). Site conditions such as steeper slopes (closer to 60%) and more concentrated runoff may have contributed to poor vigor and lower cover of *H. vulgare* in this burned area when compared to post-treatment conditions in the Horseshoe 2 burned area (C. Gibson, personal observation).

Rill densities were high and distance between rills low on several treatment transects. This may indicate that treatment implementation was not entirely effective at stabilizing soil and reducing hillslope erosion for either burned area. The timing of initial rill development, however, occurred during the first significant storms and prior to treatment. It is not possible to definitively say what effect treatments had

on hillslope stabilization because rills were not measured prior to and after the treatments. Seeded species that established on the hillslopes appeared to provide some effective ground cover on upper and lower slopes. On the Horseshoe 2 Fire, rock and litter contributed more to total EGC than all vegetation combined. Rock was the overall highest contributor to EGC for treatment and control transects. Treatment transects had higher overall vegetative cover than control transects, but this is likely due to the high frequency and cover of other vegetation detected in frames of treatment transects and low total number of control transects. Although *H. vulgare* increased EGC, uniform establishment and healthy vigor was inconsistent among treatment transects. This was particularly evident on steep slopes and where soil burn severity was high as *H. vulgare* was seldom detected in these locations and lacked robust stature that would contribute to litter cover following senescence.

On the Monument Fire, the application of agricultural straw mulch over the seed treatment contributed to EGC and slope stabilization. When considering all treatment and control transects, hillslope seeding treatment failed to meet criteria for improving EGC and has not sufficiently mitigated hillslope erosion. However, agricultural straw mulch did improve overall EGC and appeared effective at reducing hillslope erosion where slopes were gentle to somewhat moderate. Overall non vegetative effective ground cover CFI for treatments was double that of controls, indicating agricultural straw mulch treatment was successful.

The low total number of samples and the variety of slope characteristics encountered where transects were established contributed to variable hillslope results. This is particularly evident by the range of rill densities measured on treatment and control transects. It is uncertain whether hillslope rill characteristics were the result of a particularly intense localized storm or hillslope-treatment failure since data were collected following several significant storms and monsoonal moisture is highly variable. Despite a clear reduction in rill dimensions, on average, there is no significant (statistical) difference between treatment and control. A higher sample size may show the trend to be valid, but a more precise estimate of the difference is necessary to assess treatment and cost effectiveness.

Conclusions and Recommendations

Published studies of the effectiveness of post-fire seeding treatments have occurred in southern California chaparral and in various conifer ecosystems of the western United States (Beyers 2004; Robichaud 2005). Mulching (60% cover or greater) has been shown as the most effective treatment for reducing erosion, especially when protection is needed from the first storms that occur after fire (Beyers 2004). Seeding is likely to provide effective control of erosion during the first year only a third of the time (Beyers 2004). The effectiveness of seeding in Arizona may be even less due to the intensity of rainfall during monsoonal storms. Moody and Martin (2009) showed post-fire sediment yields during the first 2 years following fire are strongly tied to rainfall intensity. Rainfall regimes based on the 2-year 30-minute rainfall intensity place southeastern Arizona into the 2 highest categories (Arizona High – Horseshoe 2 Fire, and Arizona Extreme – Monument Fire) for the entire western United States (Moody and Martin, 2009). It is common that rains occur prior to treatment implementation as seen on these fires because monsoon and wildfire season overlap in Arizona. Thus, it is essential to understand if hillslope treatments are effective for this area of the country.

Initial monitoring results show that mulching on the Monument Fire appeared to be effective in reducing rill development and hillslope

erosion on gentle slopes (closer to 40%) but additional field data are needed to verify this. No evidence of wind dispersal was observed, however, poor application of straw (clumps) was observed. Implementation reports indicated some of the straw bales were not properly prepared for dispersal, which resulted in straw clumps.

Initial observations suggest that seeding does not appear to be effective in this environment especially if the objective is slope stabilization prior to first damaging storm event. To improve the current knowledge of appropriate hillslope treatments and seeding species for burned landscapes in southeastern Arizona, further data collection from transects established in September of 2011 is strongly recommended for the second and third year post-fire. In addition to data collection from the 2011 transects, establishment of additional treatment and control transects is highly recommended to provide sufficient information for comparison of treated and untreated areas within the Horseshoe 2 and Monument Fires. Additional transects of both treatment and controls will aid in identifying whether or not results are statistically significant. Measurements specific to slope degree and length will aid in identifying appropriate slope characteristics for future post-fire hillslope seeding and agricultural straw mulch treatments. This will also provide an opportunity to determine whether *Bouteloua gracilis*, *Elymus trachycaulus* or *Pascopyrum smithii* emerge in seeded sites. This is particularly important in the case of *P. smithii*, which is a rhizomatous grass that is capable of displacing native vegetation.

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Ecology and Management of Oak Woodlands and Savannas in the Southwestern Borderlands Region

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Abstract—Management of the Madrean oak woodlands and the less dense and ecologically different oak savannas must be based on sound ecological information. However, relatively little is known about the Madrean oak ecosystems in spite of the fact that they cover about 80,000 km² in the southwestern United States and northern Mexico. Emory oak (*Quercus emoryi*), the dominant tree in most stands, is usually associated with other oak and juniper species. Trees are utilized for firewood, fence posts, and construction materials and oak acorns are gathered as food by local inhabitants. The woodlands and savannas provide important habitat for listed and sensitive wildlife species and forage for livestock grazing. Tree regeneration and water consumption are important considerations. Tree harvesting has been restricted because of heavy utilization in the past but coppice management could ease the supply situation. Recreational demands and fire management concerns in the woodlands are increasing as human populations grow in southern Arizona. This manuscript reviews the ecology and management of the overstory component of oak woodlands and savannas based on relevant literature from the southwestern United States and northern Mexico.

Introduction

The Madrean woodlands and less dense savannas are characterized by mild winters and wet summers. Brown (1982) classified them as belonging to the warm-temperate forests and woodlands biotic community and lists them as Madrean Evergreen Woodlands. There is a long history of human occupation in the woodlands but management of the Madrean oak ecosystems has become more complicated in recent years because of the increasing human populations in the region and societal demands. The woodlands and savannas are noted for their beauty and biological diversity, containing representative plants and animals from the Rocky Mountains to the north and the Sierra Madre of Mexico to the south. The ecosystems provide important wildlife habitat for federally listed and sensitive and more common species in the United States. The region supports viable ranching communities and is a recreational destination for people from urban areas. Trees are utilized for fuelwood, fence posts, charcoal, and construction materials (Ffolliott and Gottfried 1992) and oak acorns and pinyon seeds are gathered as food by local inhabitants. Woodland health and local water supplies are important considerations.

The exclusion of wildfires since the late 1800s because of overgrazing and fire suppression activities has resulted in increases in

woody vegetation and fuels and a decline in herbaceous resources. Large wildfires such as the Horseshoe 2 and Monument Fires in 2011 have become common. Private and public land managers are attempting to reverse this trend by using prescribed and managed fires (Gottfried and others 2007a). Management must be based on sound ecological information. However, relatively little is known about the Madrean oak ecosystems in spite of the fact that they cover about 80,000 km² in the southwestern United States and northern Mexico. This presentation focuses mainly on the ecology and management of the tree overstory component of Madrean woodland and savanna ecosystems based on research findings and relevant literature from the southwestern United States and northern Mexico.

Description of the Woodlands and Savannas

Emory oak (*Quercus emoryi*) is the dominant tree in most stands and is usually associated with other oaks, junipers and conifer species. The biological center for the ecosystems is in the Sierra Madre of Mexico but they extend northward into the Southwestern Borderlands Region and central Arizona (Brown 1982). The Madrean oak ecosystems are representative of arid and semi-arid dryland forests and woodlands of the world (McPherson 1992). The oak woodlands and savannas reach their best development in Arizona on the foothills of higher mountains, including the Pinaleños, Peloncillos, Santa Catalinas, Huachucas, and Chiricahuas (Ffolliott and Gottfried 2008a) and are found from 1219 to 1981 m in elevation. They grade into oak-pine and pine forests at the higher elevations and grasslands or desert shrub at the lower extreme. Temperatures range from summer highs in or above 32 °C to freezing in the winter. Average annual precipitation is

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

between 254 to 508 mm, depending on elevation, with approximately half occurring during the summer monsoon period.

The woodlands and savannas are characterized by evergreen oaks generally 6 to 15 m in height. Emory oak is often associated with Arizona white oak (*Q. arizonica*), and Mexican blue oak (*Q. oblongifolia*). Gray oak (*Q. grisea*), a generally small tree, might replace white oak in western New Mexico. Silverleaf oak (*Q. hypoleucoides*) and netleaf oak (*Q. rugosa*) are found at higher elevations in the Madrean oak ecosystems. A relatively large number of additional oak species including Chihuahua oak (*Q. chihuahuensis*) and *cusi* or *encino roble* (*Q. albocincta*) occur in Mexico (Brown 1982). On many sites, Emory oak is associated with conifers such as alligator juniper (*Juniperus deppeana*), redberry juniper (*J. coahuilensis*), border pinyon (*Pinus discolor*) or Mexican pinyon (*P. cembroides*). Chihuahua pine (*P. leiophylla*) often occurs in drainages. A number of pine species are found with oak at higher elevations throughout the border region and into the oak-pine communities of Mexico (Brown 1982). The density of shrubs varies by sites. Some shrub species are velvetpod mimosa (*Mimosa dysocarpa*), redberry (*Mahonia haematacarpa*), and alderleaf mountain mahogany (*Cercocarpus montanus*). Grasses include several species of grama (*Boutelous* spp.), bullgrass (*Muhlenbergia emersleyi*), and Texas bluestem (*Schizachyrium cirratum*). More complete lists of grasses, forbs, shrubs and half-shrubs are listed in Brown (1982) and Ffolliott and Gottfried (2008a).

Differences Between Woodlands and Savannas

Ffolliott and others (2008b) examined the differences between the woodlands in the San Rafael Valley on the south side of the Huachuca Mountains in Arizona and at the lower elevation, more open oak savannas at Cascabel on the east side of the Peloncillo Mountains in New Mexico. The oak savannas were more open and variable in the spatial distribution of overstory trees than the oak woodlands. These researchers tallied seven tree species at Cascabel but only four at the San Rafael site. Emory oak accounted for 60% of the overstory trees at Cascabel and junipers 15%. On the San Rafael site, Emory oak was 89% of the overstory species composition and junipers were 1%. Arizona white oak made up 12% of the overstory at Cascabel and 9% at San Rafael. There were about 445 trees/ha at San Rafael compared to 148 trees/ha at Cascabel. The number of small and large trees was greater at San Rafael but the number of saplings was similar for the two sites. Herbaceous plant species composition was similar on the two areas with most species of grasses and forbs being perennial.

Autecology

Oak trees regenerate from seed or vegetatively from root or stump sprouts. Borelli and others (1994) studied natural regeneration on six areas of the Coronado National Forest of Arizona that had been harvested for fuelwood and grazed by livestock. Emory oak, Arizona white oak and other tree species occurred on the study sites. Fifty-six percent of the regeneration was stump sprouts, 25% were root sprouts, and 19% were seedlings. Nearly 40% of the plantlets were less than 0.3 m in height, 35% were between 0.3 and 1.0 m, and 25% were greater than 1 m but less than 1.4 m. An average of 9.2 % of the sample plots was stocked with regeneration varying from 1.2 to 15.4% depending on area. The average number of plantlets on the six areas was 240 stems/ha with a range of 29.7 to 385.5 plantlets/ha. The authors caution that the relatively low number of seedlings could have been influenced by a local drought that could have influenced acorn production. Pase (1969) reported that conditions favorable for Emory

oak establishment only occurred once every 10 years in southeastern Arizona. However, large numbers of acorns probably are consumed by mammals and insects. The study by Borelli and others (1994) was conducted in one year; however, surveys over a number of years are necessary to get a true picture of regeneration in the oak woodlands.

Nyandiga and McPherson (1992) evaluated conditions needed for germination of Emory oak and Arizona white oak. Emory oak acorns mature in about a year and then fall and germinate in July through August. Arizona white oak acorns fall and germinate in November and December. Germination generally occurred within the first 30 days for both species. These researchers found buried acorns had a greater viability than acorns that remained on the soil surface or were under litter. However, seed viability generally declined the longer an acorn was buried. Acorn viability and germination was twice as high under tree canopies as in open grassland sites. Adequate soil moisture will enhance germination and emergence (Germaine and others 1996). Germination percentages were 21 and 73% for Emory and white oak, respectively. Emory oak acorn size is correlated positively with viability, germination, and seedling size (Germaine and others 1996).

Sanchini (1981) studied growth and mortality of Emory oak and white oak in 1981 (cited in McPherson 1992; Touchan and Ffolliott 1999). He determined that mean annual diameter growth rate for Emory oak was 0.35 cm/yr and for Arizona white oak was 0.24 cm/yr. Growth-ring data, while difficult to measure in oak species, indicated that Emory oak reaches a maximum age at 200 years while white oak achieves this status in 250 years. The primary causes of death are fire, ice storms, and drought.

Ffolliott and others (2008b), in investigating the differences between woodlands and savannas confirmed that tree volumes per hectare were higher in the denser woodlands than in the savannas. Volumes of stem wood varied from less than 2 to more than 100 m³/ha. The average volumes for the two sites were about 15.86 m³/ha compared to 3.91 m³/ha. Annual volume growth rates in the dense stand at San Rafael were 0.0077 ± 0.0010 m³/ha while they were 0.0049 ± 0.0015 m³/ha at Cascabel. Growth was relatively rapid in the early and middle stages of development but declined in older trees.

Fire

Fire was the main disturbance in the Madrean oak woodlands and savannas prior to European settlement in the late 1800s. Fires probably occurred every 10-20 years at the lower end of the oak woodlands. These values were extrapolated from literature about forest fires in stands that are adjacent to semi-desert grasslands (McPherson 1992). Fire histories are difficult to determine for the oak woodlands since fire scars are not evident; however, conifers in the affected stands do display fire scars. Fire frequencies and extent have declined in the last century. The importance of fire for ecosystem health is just being recognized (Gottfried and others 2007a). Two prescribed fires and a wildfire in the savanna at Cascabel reduced overstory tree density of oaks and junipers by 21% (Ffolliott and others 2011) but resulted in significant increases in early-growing and late-growing grasses in the understory (Ffolliott and others 2012). Basal sprouting at Cascabel was observed on 37.4 % of the surviving oaks regardless of species. A wildfire in the Catalina Mountains, north of Tucson, resulted in 11.1% mortality of Emory oak and 14.2% mortality of Mexican blue oak. Emory oak produced more sprouts per tree after the fire than did Mexican blue oak (Caprio and Zwolinski 1992).

An inventory in six sites where Emory oak dominated found woody fuel loadings ranging from 0.36 to 7.82 tons/ha (Ottmar and others 2007). Measurements of litter and duff ranged from 3.26 to 10.72 tons/ha with soil surface cover of 40 to 82%. A study in pine-oak

woodlands in Arizona and northern Mexico found that sites with high fire frequencies accumulated less fuels than sites with low fire occurrences (Escobedo and others 2001). Sites in Mexico, which had 9 to 13 fires since 1900, had total fuel loadings of 11.22 tons/ha while sites in Arizona, that had from 0 to 5 fires during this period had total fuel loadings of between 22.19 and 48.43 tons/ha. Higher fuel loadings increase the potential for high-intensity stand-replacing fires.

Silviculture

The oak woodlands, and to a lesser extent savannas, were harvested heavily during the period of European settlement for mining and construction timbers, fuel for the smelters and stamp mills, fence posts, and for domestic uses by the miners and their families. The overharvesting did not eliminate the oak woodlands but resulted in a decrease in large trees and stand densities (Propper 1992). Interest in oak fuelwood increased in the 1970s and 1980s because of fuel shortages and increased oil prices. Federal lands provided 60% of the fuelwood in southeastern Arizona. Managers were forced to restrict harvesting during this period to guarantee sustainable fuelwood resources (Bennett 1992). Harvesting was limited to 3.62 m³ (1 cord)/household/year in 1992.

Fuelwood harvesters were further restricted to leaving stumps less than 15-cm in height and slash accumulations of less than 46-cm in height (Bennett 1992). Trees designated for harvesting were marked by managers in what appeared to be either single-tree selection or thinning from below depending on stand conditions and objectives. On some Forest Service districts, fuelwood harvesting was limited to trees that were smaller than 23 cm at the base. Larger trees were maintained because of their importance to wildlife.

Vigorous sprouting of oak species after the removal of the tree indicates that coppicing might form a basis to obtain satisfactory regeneration since stump and root sprouts are more common than seedlings (Borelli and others 1994). Furthermore, Touchan and Ffolliott (1999) determined that the fuelwood rotation for Emory oak sprouts to reach a diameter at root collar of 15 to 20 cm can be reduced from 100 years to approximately 30 years by thinning sprouts on a stump. Growth of residual sprouts depends on the number of stems retained. Net growth/stump is lower if fewer stems are left. While there was no difference if 1, 2, or 3 stems remained compared to the control, which was not thinned, mean annual growth per sprout increased for the single stem after its eighth anniversary.

Farah and others (2003) found that stump diameter was not a consistent factor that affected growth and volume of the thinned coppice 10 years after the thinning treatments were applied. Average growth and volume was greater for the 1-stump sprout treatment than for the other options at that time. The researchers recommended that stump sprouts be thinned initially in years 6-8 after the top is removed. Another subsequent thinning in year 15-20 should retain one sprout. Three stump-sprouts can be retained if structural diversity to benefit wildlife is a management goal.

Water Use

Water use by Emory oak has been studied with the heat pulse velocity method in the San Rafael Valley (Ffolliott and Gottfried 2000; Gottfried and others 2007b; Shipek and others 2004). The study site included an unharvested stand and an area harvested by the coppice method that included sprouts and residual uncut trees (standards). Average daily water use by mature trees averaged 17.5 liters/day,

while water use by sprouts averaged 4.0 liters/day. These averages for standards and sprouts were then extrapolated to a stand basis. The harvested stand used more than 3,150 liters/ha/yr compared to 1,900 liters/ha/yr for the uncut stand (Ffolliott and Gottfried 2000). The harvested stand contained 430 standards and 927 sprouts per hectare, while the uncut area contained 452 mature trees and 27 sprouts per hectare. Water use by the harvested site with the large number of sprouts was equivalent to 80% and water use by the unharvested site was equivalent to 45% of the annual precipitation.

Shipek and others (2004) measured water use by oak sprouts that had been thinned to retain 1, 2, or 3 sprouts per stump or not thinned. Stumps with one sprout used an average of 7.48 ± 0.31 liters/day compared to the controls that used 35.3 ± 1.72 liters/day. The values for stumps thinned to two or three stems were intermediate. Transpiration for stands with standards and sprouts thinned to 1-sprout per stump and stands with unthinned stumps was equivalent to 34% and 80% of the annual precipitation, respectively.

Ffolliott (2004) developed an annual water balance for Emory oak in southeastern Arizona. The calculations assumed that annual precipitation averaged 450 mm. This amount was reduced by 45 mm for interception by tree crowns; the remaining water was partitioned mainly to infiltration into the soil (325-350 mm), and transpiration (155-345 mm). Approximately 20-45 mm, about 4 to 10% of the input, remained for streamflow. Thirty-four to 77% of the annual precipitation was lost through transpiration.

Management Implications

Management of the Madrean oak woodlands and savannas must be based on sound ecological information. Managers must understand tree regeneration requirements to develop silvicultural prescriptions that will maintain healthy oak woodlands and savanna ecosystems. Vegetative reproduction by oaks and some junipers gives managers options that are not available to those working with non-sprouting tree species. Thinning oak sprouts will shorten the cycle for tree products. Public and private land managers are attempting to reintroduce fire into the region but these efforts also are often hindered by incomplete ecological information about fire effects and fuel conditions. These data are currently being collected on the Cascabel Watersheds and elsewhere to support the fire programs. Research on tree and woodland water use and the impacts of silvicultural treatments such as coppicing, should provide a basis for management prescriptions in oak dominated watersheds.

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Effects of Prescribed Fires and a Wildfire on Biological Resources of Oak Savannas in the Peloncillo Mountains, New Mexico

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Abstract—Private and public land managers are attempting to reintroduce fire into the ecosystems of the Peloncillo Mountains to reduce the density of woody species, increase the herbaceous plant cover, and improve the area's ecological diversity. The Cascabel Watershed Study, which includes 12 small gauged watersheds, was started in 2000 to evaluate the impacts of cool-season (November–April) and warm-season (May–October) prescribed fires on biological and physical components of the oak (*Quercus* spp.) savannas that are common to the Southwestern Borderlands Region. The Whitmire Wildfire in May 2008 modified the original experimental design. All three fire treatments resulted in low severity burns. The effects of the different fire treatments on tree overstories, herbaceous production, ground cover, selected wildlife species, and bird populations are presented. Measurements did not indicate many significant differences among treatments or with pre-fire conditions. For example, almost 78 percent of the overstory trees on the watersheds survived the fires. The main exception was a large increase in grass and total herbaceous plant production of early-growing species after the fires; annual grasses and forbs are not common at Cascabel. The fires also produced statistically significant increases in the production of late-growing grass species but the changes were not as large.

Introduction

Fires caused by lightning or Native American people were the main disturbance in the Madrean Archipelago prior to the completion of the transcontinental railroad and the introduction of large herds of cattle into the region. The range was overstocked with cattle as ranchers, often belonging to large corporations, competed with their neighbors to control access to the land (Hadley 2005). The resulting overgrazing caused a decline in the herbaceous cover that previously carried natural fires throughout the landscape. Consequently, the density of trees and woody species and debris increased and the production of herbaceous species declined. Biodiversity and productivity of many sites within the Madrean Archipelago decreased. Aggressive fire suppression by land management agencies also contributed to the decline in fires.

Ranchers in the Upper San Simon, San Bernardino, and Animas Valleys became concerned about landscape changes that were resulting

from the lack of fire. The Malpai Borderlands Group was formed in 1992 by ranchers and similar minded individuals and organizations with the goal to “restore and maintain natural processes that create a healthy landscape” (McDonald 1995:485). Officials of the Coronado National Forest and Bureau of Land Management shared a similar view about the need to reintroduce prescribed and natural fires into the region. The Coronado National Forest and Malpai Borderlands Group worked together to formulate the Peloncillo Programmatic Fire Plan to reintroduce fire into the Peloncillo Mountains that straddle the Arizona–New Mexico border. The efforts resulted in four landscape prescribed fires between 1995 and 2007. The fires occurred in the warm season prior to the monsoon rains. However, there were questions about the effects of warm-season fires on several listed species, particularly the lesser long-nosed bat (*Leptonycteris curasoae*), which requires nectar and pollen from the Palmer agave (*Agave palmeri*), and the New Mexico ridge-nosed rattlesnake (*Crotalus willardi obscurus*). Some people recommended cool-season burns that might be less detrimental. However, there was little scientific information available to support either position on the burning season or to assist managers with general knowledge about the ecology and hydrology of the ecosystem.

The U.S. Forest Service, Rocky Mountain Research Station established the Southwestern Borderlands Ecosystem Management Unit to provide public and private land managers with scientific information to support management decisions. The Cascabel Watershed Study was a research project specifically developed to answer questions about

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the impacts of burning season on oak savanna ecosystem resources (Gottfried and others 2007, 2012). The Cascabel Study can be divided into research about the biological components of the oak savanna ecosystem and research about the physical environment, for example, hydrology, erosion, and sedimentation. This manuscript will report on the effects of fires on the biological resources.

Cascabel Watershed Study

The objective of the study was to determine the impacts of cool-season (November-April) and warm-season (May-October) prescribed burning on oak savanna hydrologic and biological resources (Gottfried and others 2007, 2012). The Cascabel Watersheds consist of 12 small watersheds located in the oak savannas on the southeast side of the Peloncillo Mountains. The watersheds range in size from 20 to 60 acres covering about 451.3 acres and are located between 5380 and 5590 feet in elevation. Geology, physiology, and hydrology of the study area have been described in articles cited by Ffolliott and others (2011b) and Gottfried and others (2012). The surface soils are very gravelly or very cobbly sand or sandy clay loams (Robertson and others 2002). Emory oak (*Quercus emoryi*) is the dominant tree species with alligator juniper (*Juniperus deppeana*) a common co-dominant species. Various species of grama grass (*Bouteloua* spp.) dominate the understory. Sets of two Parshall flumes were installed in each drainage as were sediment dams, basins, and channel cross sections. Two full weather stations were set up and these are supported by seven tipping bucket rain gauges. Measurements of fire effects, soil erosion and deposition, overstory trees, herbaceous vegetation, and wildlife use were collected in each watershed at permanent sampling points arranged on transects that were located perpendicular to the stream channel. There were 35 to 45 points on each watershed depending on its size and shape for a total of 421 sampling points. Sampling procedures varied depending on the resource being monitored.

Burning Treatments and Fire Effects

After a pretreatment sampling period, the watersheds were partitioned into three groups of four with one group receiving the cool-season prescribed burn, one receiving the warm-season prescribed burn, and one group reserved as controls. The cool-season watersheds were burned by crews from the Douglas Ranger District of the Coronado National Forest in March 2008 and three of the warm-season watersheds were burned on May 20, 2008. However, the fire escaped on May 21 and burned the remaining unburned watershed, the control watersheds, and about 4,000 acres in adjacent areas. It was named the Whitmire Fire. The study design was modified appropriately to account for the wildfire treatment on five of the watersheds.

Fire severities were determined on the 421 points using a system developed by Hungerford (1996) that relates fire severity to the appearance of litter, duff, woody material, and soil condition. Classification of severity ratings at the points on each watershed were extrapolated to a watershed basis by Stropki and others (2009). They determined that 85% of the area receiving the cool-season burn had been exposed to a low severity fire, 5% had been exposed to a moderate severity fire and the remaining 10% of the area had been unburned. The spatial distribution of severities was similar on the watersheds that had been affected by the warm-season burn and the wildfire. However, Neary and others (2010) measured locations on the watersheds where high-severity fires had occurred, particularly where heavy accumulations

of organic material had accumulated. Statistical analyses indicated no significant differences in burn severities among the watersheds receiving the cool-season or warm-season prescribed burns or the wildfire. Therefore, the data were combined to compare pre-treatment and post-treatment responses of the resources.

Soil water repellency was measured using the drip test developed by Lety and others (2000). The occurrence and levels of soil water repellency was limited in extent and magnitude regardless of treatment. Approximately 90% of the area had no soil water repellency, 5% had slight water repellency, and the remaining points had moderate to strong levels of repellency.

Fire Effects On Biological Resources

Overstory Trees

The overstory tree cover was re-measured after the three fire treatments and the results were pooled because all watersheds had received low severity burns and no significant differences were detectable (Ffolliott and others 2011b). Approximately 78% of the trees that were present before the prescribed fires and wildfire initially survived. Eighty percent of the oak trees of all species and 75% of the juniper trees of all species survived. Scorch or top kill, was observed on 80% of the surviving oak and juniper trees. Thirty percent of the oak had one-third or less of the crown burned, 45% had between one-third and two-thirds affected and 25% had greater than two-thirds damaged. The relative proportions were similar for the junipers. Many of the severely burned trees might not survive into the future but basal sprouting could replace some of the dying trees. Sprouting was observed on 37% of the oaks and on 11% of the junipers. Large trees (\geq than 9 inches in diameter at the root collar) were more common on the watersheds than smaller trees and proportionally more large trees survived. The damage to large trees could be attributed to accumulations of slash and other organic material at their bases. The spatial distribution of trees at Cascabel was not impacted by the burning treatments.

Herbaceous Plant and Shrub Production

The production of early-growing and late-growing grasses was significantly greater after the three fires than before (Ffolliott and other 2012b). Depending on the event, there was a five to seven-fold increase in the production of early-growing grass species. Increases in late growing species were also significant but of a smaller magnitude. For example, the early growing grass production on the warm-season burned watersheds increased from 75 pounds/acre to 400 pounds/acre. Fire effects on the minor forb component were inconsistent. The cool-season prescribed burn did not affect forb production, but the warm-season burn and the wildfire did result in increases. Late-season forbs were not affected by the fires. Total herbaceous production, which includes grasses and forbs, increased relative to pre-treatment condition because of the dominance of grasses in the understory. The increased production has been attributed to the increased soil water availability related to reductions in tree overstory and litter and duff layers and to increased soil nutrients. The growth of shrubs generally was not affected by the burning events, except for the late-season growth of shrubs on the watersheds impacted by the wildfire.

The wildfire did produce an increase in warm season shrub production mainly because of tree sprouts. The persistence of these effects into the future is unknown.

Palmer Agave

Palmer agave, which is protected by the State of Arizona, is important because it provides pollen and nectar to the Federally listed lesser long-nosed bats that migrate into the southwestern United States in the summer (Slauson and others 1999). The agave species occurs on rocky slopes in the oak savannas of the Southwestern Borderlands region. Concern about damage to this species was one reason for the Cascabel study. Information about the agave population on the watersheds was not collected prior to the burning events but a survey was conducted on the plots afterwards (Ffolliott and others 2010). The agave was found on 12.9% of the plots visited after the fires. The occurrence of agave could not be related to topography, soil surface characteristics, or to surrounding vegetation. No burned agave plants were found on the sample plots but an unknown number of burned or partially burned plants were observed outside the established plots. There was no pattern in the location of dead or injured agaves. Average agave production on the watersheds following the fires was about 0.25 pounds/acre with a range of a trace to 16.7 pounds/acre on individual watersheds. Ffolliott and others (2010) could not conclude if the Cascabel treatments had an effect on the Palmer agave population because of the lack of pretreatment data.

Wildlife

Mammals—The prescribed burns and the wildfire did not affect the use of the watersheds by two keystone species—Coeus white-tailed deer (*Odocoileus virginianus couesi*) and desert cottontail (*Sylvilagus audubonii*) (Ffolliott and others 2012a). Fecal pellets were counted in the spring and autumn at the permanent sampling points. The area around each point was cleared after each survey. There were no differences in deer or cottontail use related to the three low-severity fires. However, counts in the spring after the winter season were higher than counts in the autumn after the monsoon rains. It appears that the deer use the savannas during the winter when weather conditions are relatively mild and move into the higher, cooler, and moister elevation woodlands and forests during the warm summer. The same pattern of higher spring use by the cottontail was observed. It was hypothesized that this could be related to high birth rates during the winter and subsequent predation during the summer.

Birds—Surveys of bird species and numbers were conducted around a subset of sampling points on each watershed during the spring and autumn before and after the fires (Ffolliott and others 2011a). Bird observations were made for 5-min at each point following the procedures described by Braun (2005). Some species were observed frequently while others were tallied occasionally. More bird numbers and species were tallied in the autumn after the monsoon rains than in the spring after the winter rains. This difference could be related to greater availability of food following the monsoon period. Some common sightings in both seasons included the Ash-throated Flycatcher (*Mylarchus cinerascens*), Bushtit (*Psaltriparus minimus*), Mexican Jay (*Aphelocoma ultramarina*), Turkey Vulture (*Cathartes aura*), and Mourning Dove (*Zenaidura macroura*). A more complete list of species is presented in Ffolliott and others (2011a). Calculations of bird species richness, species diversities, and evenness for both seasons suggest that the three fire treatments had little consistent effect on the ecological diversity at Cascabel. It was difficult to isolate the impact of the prescribed burns or the wildfire because of the large variability in tallies of species and numbers.

Herpetofauna—No New Mexico ridge-nosed rattlesnakes were encountered on the Cascabel Watersheds. However, 8,951 lizards

belonging to 10 species were identified at Cascabel between 2004 and 2010 (Goode 2011, Unpublished report). It is difficult to draw conclusions about the effects of fire on the lizard population because of the variability of rainfall, vegetative cover, and lizard numbers on the plots. A preliminary conclusion was that the fires did not affect the lizard population.

Conclusions

The Cascabel Watershed Study was established to determine the impacts of cool-season and warm-season prescribed fires on the ecology and hydrology of Madrean oak savannas. The effect of burning season on natural resources was an important concern among public and private land managers. The Whitmire Wildfire in 2008 modified the statistical design so that the current analyses evaluate the impacts of cool season and warm season prescribed fires and a wildfire on the biological and hydrologic resources. This paper discussed the impacts on the biological resources at Cascabel. The physical aspects of the study are reported elsewhere (Gottfried and others 2012).

The three fire treatments, regardless of prescription or timing, burned at low severity and produced similar impacts on the biological resources. The data from the treatments were combined and subsequent analyses compared pre-treatment with post-treatment conditions. The reduction in tree survival was minor and inconsequential in terms of management options (Ffolliott and others 2011b). The production of grasses and general herbaceous cover was the only resource that exhibited a significant change related to the fires and that was a positive increase in production (Ffolliott and other 2012b). The fires did not affect deer or cottontail use of the total area, probably because of a lack of significant changes to the tree cover. The lizard population probably was not affected by the fires but that needs further analyses, and no fire effects could be determined from the bird surveys.

It is concluded that the low-severity fires at Cascabel did not have major impacts on most biological resources of the oak savannas. Fire managers might use the Cascabel Watershed results as an initial guide since there is little information available on fire effects in the region's oak savannas, but realize that different pre-fire conditions or weather could produce other results (Ffolliott and others 2011b). Prescribed fires ignited under warmer and drier conditions or in denser stands of trees and brush could burn more severely and have more drastic impacts. Managers will have to consider all options as they develop and execute programmatic fire plans.

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Impacts of Wildfire on Wildlife in Arizona: A Synthesis

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Abstract—Due to a century of fire suppression practices, the Madrean Archipelago regions in Arizona have accumulated excessive fuel loads that increase wildfire sizes, intensities, and frequencies. Wildfire induced structural changes in forest ecosystems can either benefit or adversely impact wildlife species. Therefore, it is imperative to understand how wildlife species react to such ecosystem changes after wildfires in both the short-term and long-term time periods. We examined scientific literature to determine wildlife distribution, abundance, elevational migration, and behavioral changes (i.e. how wildlife use resources post-fire) in response to wildfire. Understanding the impacts of wildfire-induced habitat fragmentation and creation of edge effects on wildlife species will provide information about overall forest condition and forest management practices.

Introduction

The Madrean Archipelago stretches from the Mogollon Rim in northern Arizona to the Sierra Madre Occidental in northwestern Mexico (Ffolliott and others 1995; Warshall 1995). The archipelago consists of 40 Sky Islands, which are a series of isolated mountain ranges that contain several vegetative zones that extend upwards from flat, low-lying arid regions (Ffolliott and others 1995; McLaughlin 1995). Sky Islands have geographically isolated species since the last glaciopluvial event and therefore harbor elevated species diversity and richness (Lomolino and others 1989; Warshall 1995). The 19 Sky Island complexes in Arizona provide refuge for the great diversity of mammals, reptiles, and ants (Warshall 1995). However, biodiversity of endemic montane species is negatively impacted by grazing, soil erosion, introduced exotic species, habitat fragmentation and wildfire. Fire suppression practices for over a century have caused an increase in fuel loads that allow wildfires to increase in frequency, intensity, and size (Covington and Moore 1994; Sackett and others 1994; Swetnam 1990). These large, intense fires are rapidly changing ecosystems and these cover type conversions may have adverse impacts on flora and fauna. The occurrence of such large scale, high intensity wildfires is predicted to continue to increase in the region exacerbated by climate change (Westerling and others 2006). Herein, we briefly review the historical pattern of fire and the effects of wildfire on wildlife in Arizona.

Wildfire Impacts

Historical Pattern

Before 1900, low-severity ground fires were common and burned every 2-15 years (Brown and Smith 2000; Kiltie 1989; Swetnam and

Baisan 1996b; Thomas and McAlpine 2010). Since fire suppression practices altered the natural fire regime in Arizona, catastrophic stand-replacing wildfires are increasing in frequency and have burned over 1.5 million ha within the last decade (fig. 1; Southwest Coordination Center 2012). Flora and fauna species may not be adapted to these increasingly large and intense wildfires (Swetnam and Baisan 1996b). Fires can create a mosaic of burn severities across the landscape due to varying fuel load accumulations and other factors, particularly, in montane forests where pine-oak, mixed-conifer, and ponderosa pine (*Pinus ponderosa*) dominate the upper vegetative zones. Depending on the size of burn severity patches, these mosaics can fragment habitats, create edge effects, and change vegetative structure and composition. Therefore, understanding the impacts of these mosaic patterns of burn severities on wildlife species is ecologically important.

Wildlife

Common wildfire impacts on wildlife include direct mortality, injury, increased predation from lack of cover, or starvation from lack of food availability (fig. 2; DeBano and others 1998; Ream 1981). Generalist species, such as coyotes (*Canis latrans*) and great horned owls (*Bubo virginianus*), are typically not significantly impacted by wildfires since they may exhibit prey switching if other food resources are limited. Specialist species are more likely to be adversely impacted by wildfire than generalist species since specialists typically concentrate on a single resource. The ability for wildlife to survive wildfires depends on food availability, cover, mobility, behavior, and structural diversity (DeBano and others 1998; Lyon and others 1978; Patton 1992). Structural diversity is the uniformity, severity, size, intensity, season, and duration of the fire that creates edges between adjacent vegetative types (edge effect), creates snags that provide cover or cavities for use by wildlife, and creates environmental heterogeneity through the mosaic effect (DeBano and others 1998; Lyon and others 2000; Wright and Bailey 1982). Wildlife can be impacted by structural diversity if a wildfire burns uniformly at a moderate to high intensity rate across a large area due to lack of vegetation and cover throughout that landscape. Some highly mobile wildlife species will be able to travel long distances to emigrate from those areas; however, other wildlife species may try to emigrate but cannot get out of the

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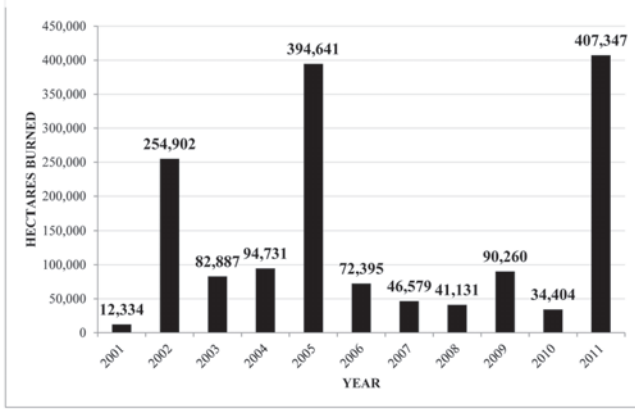


Figure 1—Hectares burned in Arizona 2001-2011.

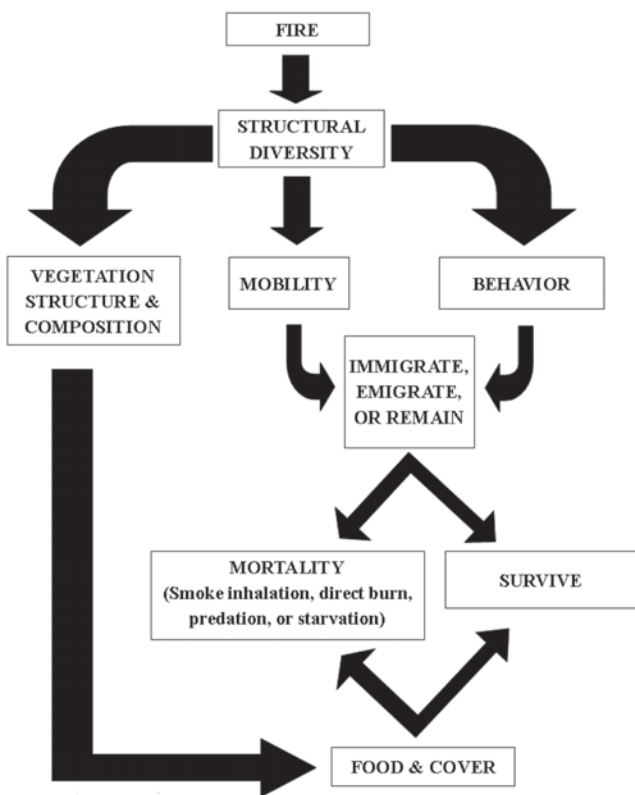


Figure 2—Impacts of fire on wildlife species. Arrows mean influences that can impact wildlife species.

moderate to high-severity patch. Ultimately, those species that cannot find their way out can potentially die of starvation or predation.

Most wildlife deaths during wildfires are due to smoke inhalation, direct burn, and behavior such as the inability or reluctance to evacuate (Bock and Lynch 1970; Buech and others 1977; Bulan and Barrett 1971; Chew and others 1959; Harrison and Murad 1972; Lyon and others 2000). Direct burns are a result of a wildfire that moves extremely fast and burns at an exceptionally high intensity, usually >63 °C, which is lethal to both small and large wildlife species (DeBano

and others 1998; Howard and others 1959). Some wildlife species will not leave nests, burrows, cavities, or dens during fire, which subjects them to smoke inhalation and possibly death by suffocation. However, many fossorial mammals can survive wildfires since most burrow systems are extensive, subterranean tunnels that protect against heat intensity (Erwin and Stasiak 1979; Lyon and others 2000; Sutherland and Dickman 1999; Vernes 2000).

Wildfires that burn during the spring typically impact more wildlife species than wildfires that burn during any other season. Because spring is the time when breeding occurs for a majority of species, fires that erupt during this critical period can destroy nests, dens, burrows, or cavities and/or make them more open to predation by opening tree canopies or understory cover (Ward 1968). Adults are sometimes unable to emigrate from nests, dens, burrows, or cavities during fire due to the lack of mobility of offspring (Koprowski and others 2006; Lyon and others 2000). During fire, young animals are more prone to injury or mortality than adults; however, wildlife with high reproduction rates allow faster population recovery post-fire (Lyon and others 2000).

Granivores and Insectivores—Wildfire impacts granivore and insectivore species through loss of resources; however, some of these species respond positively to wildfires due to adaptation to open space or added food and cover over time (Lyon and others 2000). Birds in southeastern Arizona such as mourning doves (*Zenaidura macroura*), vesper sparrows (*Pooecetes gramineus*), savannah sparrows (*Passerculus sandwichensis*), lark sparrows (*Chondestes grammacus*), horned larks (*Eremophila alpestris*; Bock and Bock 1992), and hairy woodpeckers (*Picoides villosus*) in northern Arizona forests (Covert-Bratland and others 2006) are typically found in burned areas due to an increase in seed production and insect infestations post-fire (Bock and Bock 1992, Covert-Bratland and others 2006). Woodpeckers emigrate into high-severity burns where most trees have been killed due to an abundance of insects and cavities (Lyon and others 2000), but home range sizes increase over time since the fire, which indicates that initially habitat quality increases but then is reduced over time (Covert-Bratland and others 2006). Other birds in southeastern Arizona such as Eastern meadowlarks (*Sturnella magna*), Cassin’s sparrows (*Aimophila cassinii*), Botteri’s sparrows (*A. botteri*), and grasshopper sparrows (*Ammodramus savannarum*), avoid burned areas for 2-3 years post-fire due to lack of grass and shrub cover (Bock and Bock 1992). Most birds will typically escape fire due to their extreme vagility (Erwin and Stasiak 1979; Gelluso and others 1986; Hakala and others 1971; Lyon and others 2000; Peres 1999); however, most ground-dwelling birds are likely to be adversely impacted by fire (Lyon and others 2000).

Small mammals also respond differentially to wildfire. Lack of food and/or predation are typical causes for small mammal decline within the first 2 months post-fire (McMurry and others 1996; Simons 1991). At Fort Huachuca Military Reservation, presence of species did not change post-fire for Merriam’s kangaroo rat (*Dipodomys merriami*), silky pocket mice (*Perognathus flavus*), American deer mice (*Peromyscus maniculatus*), hispid pocket mice (*C. hispidus*), Northern grasshopper mice (*Onychomys leucogaster*), and Southern grasshopper mice (*O. torridus*), which indicates that these species did not emigrate from burned areas immediately post-fire (Litt and Steidl 2011). However, presence decreased on burned areas for Northern pygmy mice (*Baiomys taylori*), fulvous harvest mice (*Reithrodontomys fulvescens*), and Arizona cotton rat (*Sigmodon arizonae*), which may indicate direct mortality, predation from lack of cover, starvation from lack of food, or emigration to unburned areas immediately post-fire (Litt and Steidl 2011; Steidl and Litt 2009). Arizona cotton rat, fulvous harvest mice, and Merriam’s kangaroo rat increased in abundance in

burned areas while silky pocket mice, Northern grasshopper mice, and desert pocket mice (*Chaetodipus penicillatus*) decreased in abundance in burned areas (Litt and Steidl 2011; Steidl and Litt 2009). Abundances of yellow nosed cotton rats (*S. ochrognathus*), hispid pocket mice, and Northern pygmy mice did not change post-fire (Litt and Steidl 2011). In the Mazatzal Mountains, Ord's kangaroo rat (*D. ordii*), Merriam's kangaroo rat, cactus mice (*Peromyscus eremicus*), and pocket gophers (*Thomomys spp.*) use burned areas more than unburned areas, whereas Bailey's pocket mice (*C. baileyi*) use unburned areas more than burned areas (Monroe and others 2004). Merriam's kangaroo rats respond positively to burned areas due to being a generalist species and favoring open areas, which adversely impacts Bailey's pocket mice due to lack of cover (Price 1978; Rosenzweig and others 1975; Simons 1991).

Wildfire may adversely impact tree squirrels due to reduction of nests, cavities, and food resources (Kirkpatrick and Mosby 1981) and through creation of edge effects and fragmented habitat, but most squirrels temporarily emigrate during wildfire and are successful in avoiding wildfire (Bendell 1974). However, endangered Mt. Graham red squirrels (MGRS; *Tamiasciurus hudsonicus grahamensis*) in the Pinaleno Mountains are adversely impacted by large, intense stand-replacing wildfires since these types of catastrophic fires did not occur historically (Koprowski and others 2006). After the Nuttall fire in 2004, surveys were conducted to determine effects of wildfire on MGRS (Sanderson and Koprowski 2009). No MGRS carcasses were found but seven resident squirrels were not relocated post-fire (Koprowski and others 2006). However, a charred and dead Abert's squirrel (*Sciurus aberti*) was found (Greer, personal communication). Mt. Graham red squirrels require a midden, a long-term central cache site, for winter survival. These midden sites are typically located in dense, live portions of forest where greater amounts of seedfall occur, which may be severely impacted by catastrophic wildfires that opens forests and kills trees (Koprowski and others 2006; Wood and others 2007). The presence of small localized fire does not immediately trigger abandonment, as a MGRS was observed to continue to use a smoldering nest tree that had received a lightning strike (Merrick and others 2010). After surviving the direct effects of wildfire, many squirrel species respond positively to fire with equivalent or superior survival, decreased home range size in areas of reduced fire intensity and in areas where the fire did not reach the canopy, or use of burned areas more than unburned areas (Blount and Koprowski 2012; Dumas and Koprowski 2012; Gwinn 2011; Leonard and others 2010; Pasch and Koprowski 2011). Abert's squirrels introduced to Mt. Graham used areas within the perimeter of severe burns more than endangered MGRS (Gwinn 2011). Mexican fox squirrels (*S. nayaritensis*) used areas that experienced low-severity burn more than unburned areas and those that experienced higher burn severity, which indicates that this species is adapted to the low-severity fires that were historically experienced in the Chiricahua Mountains of southeastern Arizona (Dumas and Koprowski 2012).

Lizards are typically impacted by wildfire due to changes in vegetative structure and composition (Means and Campbell 1981; Russell and others 1999). In the southern Mazatzal Mountains near Four Peaks, lizard abundances in burned areas were greatest in chaparral and forest due to an increase in insect infestation post-fire (Cunningham and others 2002). In burned chaparral, Sonoran spotted whiptail (*Cnemidophorus sonorae*), Gila spotted whiptail (*C. flagellicaudus*), eastern fence lizard (*Sceloporus undulatus*), and ornate tree lizards (*Urosaurus ornatus*) were most abundant post-fire (Cunningham and others 2002). In unburned chaparral, collared lizards (*Crotaphytus collaris*) and short horned lizards (*Phrynosoma douglassi*) were most abundant (Cunningham and others 2002). Other lizards such as

western whiptail (*C. tigris*), plateau striped whiptail (*C. velox*), and little striped whiptail (*C. inornatus*) use both unburned and burned chaparral (Cunningham and others 2002). However, western whiptail lizards decrease in abundance over time while other lizards increase in abundance in burned chaparral (Cunningham and others 2002). In burned forest, plateau striped whiptail, ornate tree lizard, Sonoran spotted whiptail, western whiptail, Gila spotted whiptail, collared lizards, western banded gecko (*Coleonyx variegatus*), and Great Plains skink (*Eumeces obsoletus*) were most abundant post-fire (Cunningham and others 2002). In unburned forest, short horned lizards and Madrean alligator lizards (*Elgaria kingi*) were most abundant (Cunningham and others 2002). Eastern fence lizards and little striped whiptail use both unburned and burned forest (Cunningham and others 2002).

Herbivores—Herbivores are primarily impacted by wildfire in the short-term due to loss of vegetation structure and composition. For this reason, most herbivores select unburned areas initially post-fire. However, once vegetative regrowth occurs, most herbivores will immigrate to burned areas. In the San Francisco Peaks, elk (*Cervus canadensis*) frequently use high-severity burn areas once aspen resprout occurred (Bailey and Whitham 2002). High-severity burn areas regenerate aspen ramets faster and with greater biomass than unburned, low-severity, and moderate-severity sites (Bailey and Whitham 2002). Elk continually graze high-severity burn areas for up to 3 years post-fire, which decreases aspen biomass, but aspen biomass increases by threefold in moderate-severity burn areas since elk herbivory was not prevalent (Bailey and Whitham 2002). Desert bighorn sheep (*Ovis canadensis mexicana*) in the Santa Catalina Mountains also use burned areas that open dense understory (Cain III and others 2005), since vegetative removal increases their visibility and ability to avoid predators (Etchberger and others 1989; Krausman and others 1996, 2001; Wakelyn 1987). Unburned areas with excessive, dense understory will be abandoned by sheep because these areas become unsuitable for sheep persistence (Krausman and others 1996). Burned areas had higher visibility measurements than unburned areas because unburned areas had an increase of vegetation over a 32-year period of fire suppression (Krausman and others 1996). Collared peccaries (*Pecari tajacu*) on the Three Bar Wildlife Area avoided burned desert scrub and chaparral areas for 1-2 years post-fire due to lack of cover and food resources such as cactus, acorns, and legumes (O'Brien and others 2005). Lower elevations in unburned chaparral and desert scrub were used more frequently by peccaries post-fire because these areas provided more thermal cover (O'Brien and others 2005). However, after 2 years, burned chaparral vegetation regenerates and provides as much cover as unburned chaparral (O'Brien and others 2005). Conversely, burned desert scrub vegetation did not completely recover, which indicates that these areas did not provide adequate cover for peccaries, even after 4 years post-fire (O'Brien and others 2005). White-throated woodrats (*Neotoma albigula*) in the Mazatzal Mountains were found to use unburned areas more than burned areas post-fire (Monroe and others 2004). Fire likely kills many woodrats since they usually do not emigrate from nests during fire (Quinn 1979; Simons 1991; Tevis 1956); however, woodrats that do emigrate during fire are found more frequently in unburned areas (Monroe and others 2004).

Carnivores and Omnivores—Wildfire impacts on carnivores and omnivores are rarely studied because most are generalists that are vagile and exhibit prey switching when main food resources are limited. Female black bears (*Ursus americanus*) in the Mazatzal Mountains used unburned patches 90% of the time (Cunningham and others 2003). Before the fire, female black bears with cubs used higher elevations to avoid males from preying on their offspring;

however, females with cubs switched use from higher elevations to lower elevations post-fire likely due to lack of food resources and cover (Cunningham and Ballard 2004). Black bear survival post-fire is high; however, juvenile and female populations and cub recruitment declined (Cunningham and Ballard 2004). Male black bears primarily use burned areas and have larger home ranges post-fire (Cunningham and Ballard 2004), which indicate that resources were lacking in burned areas (Cunningham and others 2003). In the southern Mazatzal Mountains, gray foxes (*Urocyon cinereoargenteus*) use unburned areas more frequently than burned areas, while coyotes use both unburned and burned areas (Cunningham and others 2006). Gray foxes primarily use unburned areas because soft mast made up the majority of their diet (Cunningham and others 2006). Since over 90% of vegetation was lost post-fire, this influences gray foxes to decline in abundance likely due to starvation (Cunningham and others 2006). Coyote abundance did not seem to be impacted by wildfire, likely due to being a generalist species and an opportunistic predator (Cunningham and others 2006). In the Coconino National Forest and Coronado National Forest, Mexican spotted owls (*Strix occidentalis*) were not adversely impacted in the short term by presence or severity of wildfire, even though these forests have experienced catastrophic stand-replacing wildfires in the past (Jenness 2000). This outcome is likely due to owls being extremely vagile, generalist species.

Discussion

Wildfire can either positively or adversely impact wildlife species depending upon how intensely the fire burns, size of the burn severity patches, and the mosaic pattern left behind. Unfortunately, most studies do not incorporate these factors into their research design. Most forest dwelling wildlife species in the southwest are likely adapted to frequent, low-severity ground fires (Brown 1982; Humphrey 1974; Marshall 1963; Wright and Bailey 1982); however, increased fuel load accumulations from a century of fire suppression practices have created large, high-intensity crown fires and most wildlife species have not yet adapted to these conditions (Bendell 1974; DeBano and others 1998; Singer and Schullery 1989). Wildfire impacts wildlife species by reduction or loss of food and cover and overall changes in structural diversity (Lyon and others 1978; Lyon and others 2000; Patton 1992). Vagile, generalist species are probably only impacted by wildfire in the short term, since they will exhibit prey switching when resources are limited thus being able to find other food resources throughout a mosaic of burn severity types. Specialist and small, non-fossorial species are likely to be impacted the greatest by wildfire via direct mortality and loss of food resources and cover (DeBano and others 1998; Erwin and Stasiak 1979; Lyon and others 2000; Sutherland and Dickman 1999; Vernes 2000). Wildfires tend to create a more open forest understory and a mosaic of burn severities across the landscape that can fragment habitats, create edge effects, and change vegetative structure and composition. Some wildlife species tend to thrive in these areas, while others are hindered because they require cover to protect them from predation. Most mammal and avian predators increase their use of burned areas, which further exacerbates mortality of wildlife species post-fire (Lawrence 1966, Lyon and others 2000).

Management Implications

Fire is successful at reducing fuel loads, an important objective where fuel has accumulated to unprecedented levels, but may have adverse impacts on some wildlife species. Most studies do not distinguish use in burned areas. We suggest that research design must include use

versus availability models to produce more significant results. We are also suggesting that burn severities must also be distinguished. This will allow managers to better understand how various burn severities can impact wildlife. Managers must understand life histories of individual wildlife species to understand how they may be impacted by wildfire and manage accordingly; however, effects of fire on many wildlife species are relatively unknown. Recent wildfires in Arizona emphasize our lack of knowledge about the short-term and long-term effects of wildfire on wildlife, while providing a unique opportunity to undertake such studies.

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Burned Saguaro: Will They Live or Die?

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Abstract—Thousands of acres of giant saguaro (*Carnegiea gigantea*) habitat in the Sonoran Desert have been scorched by fire in recent decades. Resource managers struggle to maintain scenic landscapes featuring majestic saguaro faced with the challenges of fire, non-native species invasion, and recreational needs of millions of annual visitors. Successfully managing this iconic plant community requires understanding its fire resilience or intolerance. We compared survival of 162 saguaro 10 years after two wildfires on the Mesa Ranger District, Tonto National Forest, Arizona. Six 350-m point-quarter transects were randomly placed among burned and unburned areas. Four individual saguaro were measured at each of 8 points spaced 5 m apart along each transect. Ten years post-fire, high saguaro mortality and stunted growth were observed in both burns. Average saguaro mortality was 32% with apical height growth of 0.9 m after the Vista View fire compared to 51% and 0.6 m after the higher severity River fire. Unburned areas had 7% saguaro mortality and apical growth of 1.13 m. High compared to low fire severity burned areas nearly doubled saguaro mortality and stunted the growth of surviving saguaro by 30%. Our results suggest that maintaining strict fire prevention and suppression measures in high value saguaro habitat may be necessary to ensure that expansive vistas will continue to include this iconic cactus.

Introduction

Annually, about six million visitors travel to the Sonoran Desert on the Tonto National Forest, Arizona, to view a tourism favorite, the giant saguaro cactus (*Carnegiea gigantea*). Sadly, thousands of acres of this cactus's thorn-shrub vegetation community have been scorched by fire during the last 4 decades (Narog and others 1995). Because of its slow growth and great size at maturity, the saguaro and its habitat will take a century or more to return to their previous grandeur after fire. Presently, maintaining and restoring this ecosystem poses a multidimensional problem. Resource managers of the saguaro thorn-shrub habitat face challenges managing this ecosystem such as recurrent fire, uncertain saguaro retention and regeneration, invasion of non-native species (Cave and Patten 1984; D'Antonio and Vitousek 1992; Tellman 2002) and the recreational needs for millions of annual visitors.

Natural saguaro attrition and recruitment can be highly variable. Turner (1990) followed two different saguaro populations over 29 years that had 26 and 80% mortality; recruitment was correspondingly 11% vs. 76%. He found that episodic recruitment corresponded to heavy precipitation years. Humphrey (1984), and more recently Brooks and Pyke (2002), noted how effects of human activities, such as grazing, shortened fire return intervals, and increases in invasive plants, have reduced biodiversity in all North American deserts. High fire mortality and difficulties predicting future fire and climatic events

further complicate saguaro conservation. Comprehensive studies of the ecology and natural history of saguaro have been done (Pierson and Turner 1998; Robichaux 1999; Steenbergh and Lowe 1971, 1977, 1983; Turner and others 1995). However, long-term post-fire quantitative work using measures of fire injury, mortality and recovery for saguaro and other Sonoran Desert plants are poorly documented (Wilson and others 1995, 1996, 1998). Reasons why some fire-injured saguaro persist over time and survive while others perish still need to be determined. Recent research has included studies on the impacts of fire and invasive species on soil ecology (Steers and Allen 2011) and the use of GIS relational database management systems for fire history analysis (Swantek and others 1997). Broadening the knowledge and scope of environmental changes with an expanded database and increasing the resource tools available for measuring change in this thorn-shrub desert habitat will facilitate the understanding of fire impacts on saguaro and its ecosystem's response to burning.

We've been studying the long-term effects of fire on saguaro populations following two fires that burned thousands of hectares on the Mesa District, Tonto National Forest, Arizona (Narog and others 1995). During May 1993, the Vista View fire burned 1,200 ha (3,000 ac), including scenic vistas of saguaro along Highway 87. Nearby, during July 1995, about 4,047 ha (10,000 ac) of saguaro habitat burned in the high intensity River fire. Post-fire saguaro injury and mortality were apparent in both areas. However, why some burned saguaro lived and others died was not always clear (fig. 1). In this paper we present data on the growth and mortality of individual saguaro from the first 10 years after these two wildfires.

Methods

The 1993 Vista View and 1995 River wildfires charred saguaro habitat in an area known as The Rolls, near Four Peaks Road on the

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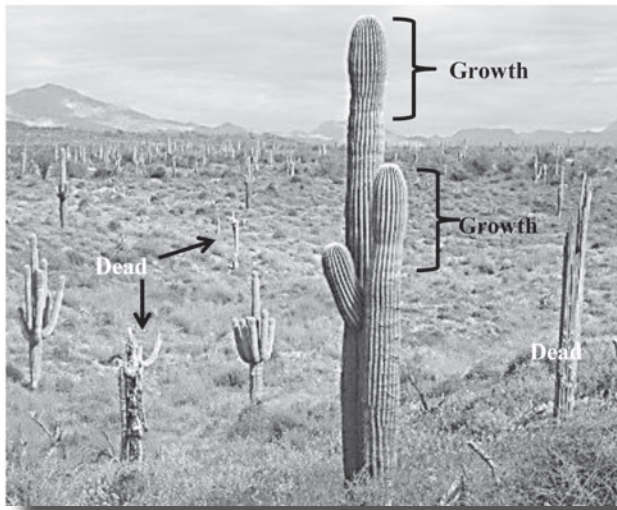


Figure 1—Some post-fire saguaro survived and grew while others nearby died. Photo was taken 10 years after the 1995 River Fire, Tonto National Forest, Arizona.

Tonto National Forest, Arizona (Wilson and others 1995). Saguaro measurement data were collected along six 350-m point-quarter line transects randomly placed in and near the two adjacent wildfires (one control and five within fire perimeters; fig. 2a). Transects were oriented north to south, and both burned and unburned saguaro plants were represented in the study population. Eight points, located at 50 m intervals, were sampled along each transect. At each point, the nearest saguaro in each quarter was chosen for measurement (fig. 2b). Saguaro dimensions, fire exposure, and mortality were documented over time for 162 individual saguaro. The saguaro is highly variable in the number of branching arms each plant has and the contributions that the arms give to the total biomass of each cactus. Therefore, to estimate how growth differed among the burned and unburned saguaro individuals, we simply used maximum height gain or loss for comparisons. Transects had different numbers of saguaro due to overlap from previous 50 m sample points, variable topography, irregular burn perimeters, and roads. Fire severity was defined after personal communications with fire fighters who fought the fires and the Tonto National Forest Resource Officer as well as personal observations made of fuel reduction on our post-fire study.

Individual cacti were remeasured at each successive visit to the study area. Unburned transects were measured in 1994, 1997, 2000, 2003 and 2005. Transects in the Vista View fire perimeter were visited in 1994, 1998, and 2003 (1, 5, and 10 years post-fire). The River fire transects were measured in 1997, 2000, and 2005 (2, 5, and 10 years post-fire).

Results

Data from unburned saguaro sampled from 1994 through 2005 are presented in table 1. Tables 2 and 3 show data from each saguaro exposed to fire over 10 years later. Transect 2 (fig. 2b) was unburned and had no recorded fire history. Some saguaro on Transect 3 escaped burning, but others were subjected to varying fire severity by the River fire. The River fire was less intense at its perimeter, which included part of Transect 3. More intense fire behavior was observed by fire personnel in Transect 4.5 (Kerr, personal communication).

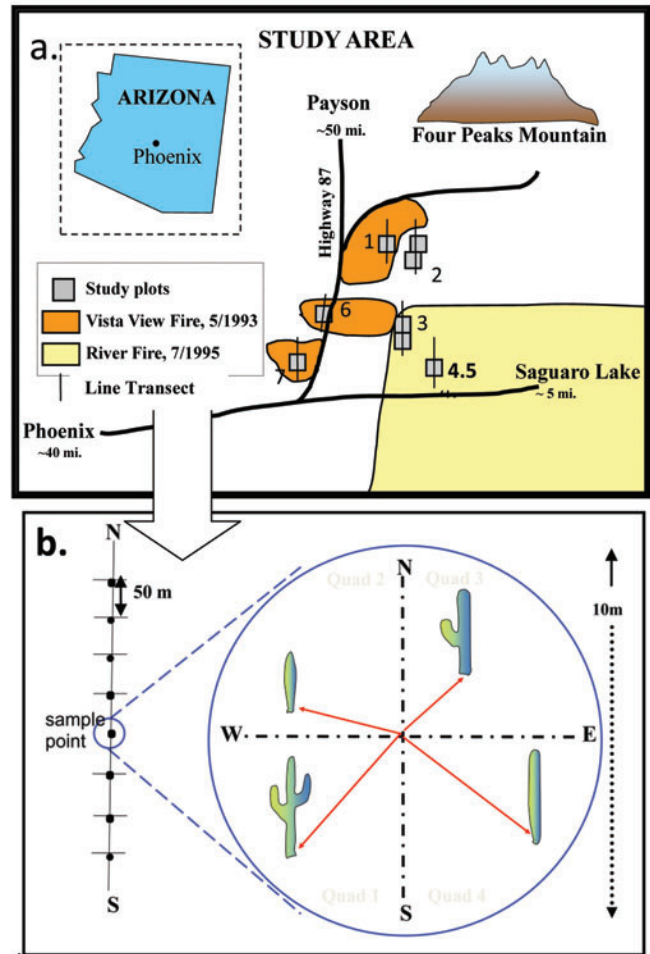


Figure 2—(a) Location of study and fire perimeters on the Mesa District, Tonto National Forest near Phoenix, Arizona. (b) Saguaro were sampled every 50 m along randomly placed 350-m transects in burned and unburned areas.

Observational assessment of fire intensity correlated well with the amount of fuel reduction found during our post-fire measurements. Transect 6 showed the greatest fire severity among the three transects burned in the Vista View fire (fig. 2a). Burn scar measurements on individual saguaro (Narog and Wilson unpublished data), in addition to the presence of abundant shrub and cactus skeletons, illustrated the lower intensity of the Vista View fire compared to most of the River fire.

Saguaro mortality and growth during the first 10 years after fire differed among the unburned, low fire severity, and high fire severity areas. We observed 7% mortality after 10 years of saguaro growing in unburned areas (table 4). Saguaro mortality was 5 to 10 times greater in burned than in unburned areas. Saguaro mortality for the three transects on the lower severity Vista View fire averaged 32%. Saguaro mortality varied on the River fire from 22% along Transect 3 (low severity area) to 77% for Transect 4.5 (high severity area) (table 4). Smaller saguaro had greater mortality than larger; most individuals less than 4 m in height did not survive either fire.

Height measurements of individual saguaro ranged from less than 1 m to over 10 m. Saguaro height growth averaged 1.1 m per plant over 10 years in the unburned area (table 1) compared to 0.9 m for saguaro burned in the Vista View fire (table 2) and 0.6 m for the River

Table 1—Ten year point-quarter data for unburned Transect 2 and the unburned portion of Transect 3 showing saguaro live and dead heights (m) measured between 1994 and 2005, Tonto National Forest, Arizona (N = 30).

Saguaro	1994		1997		2000		2003		2005	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
2	6.5	--	7.0	--	7.1	--	7.2	--	7.4	--
23	6.5	--	5.8	--	6.2	--	6.4	--	6.4	--
24	2.4	--	2.9	--	3.5	--	3.8	--	4.2	--
25	3.2	--	3.4	--	4.2	--	4.5	--	4.8	--
26	3.8	--	4.0	--	4.4	--	4.6	--	4.8	--
27	6.5	--	7.5	--	8.7	--	9.0	--	9.2	--
28	5.4	--	6.1	--	6.3	--	6.7	--	7.3	--
29	8.5	--	9.0	--	9.5	--	10.1	--	10.4	--
212	7.0	--	8.0	--	8.2	--	8.5	--	8.6	--
213	4.8	--	3.5	--	3.5	--	3.5	--	3.7	--
216	7.0	--	7.7	--	7.8	--	8.1	--	8.3	--
217	6.5	--	7.3	--	7.5	--	8.0	--	8.2	--
220	5.0	--	5.6	--	5.8	--	6.0	--	6.0	--
222	4.5	--	4.8	--	5.1	--	5.1	--	5.4	--
223	4.0	--	4.7	--	5.2	--	6.2	--	6.0	--
224	0.8	--	1.1	--	1.5	--	1.8	--	2.2	--
225	7.0	--	7.7	--	7.6	--	7.8	--	8.1	--
227	6.0	--	6.1	--	6.5	--	6.4	--	3.7	--
228	3.8	--	4.1	--	4.8	--	5.2	--	5.8	--
229	2.4	--	3.3	--	4.2	--	4.6	--	5.0	--
230	5.0	--	5.7	--	6.0	--	6.2	--	6.6	--
232	5.5	--	6.3	--	6.1	--	6.4	--	6.7	--
221	3.6	--	3.6	--	--	3.2	--	3.3	--	3.1
21	--	2.5	--	2.5	--	--	--	--	--	--
333	5.5	--	6.0	--	6.2	--	--	--	7.4	--
335	2.0	--	2.3	--	2.9	--	--	--	3.6	--
336	2.1	--	3.4	--	3.4	--	--	--	4.2	--
342	4.5	--	4.7	--	5.1	--	--	--	5.5	--
350	3.7	--	4.2	--	4.9	--	--	--	6.1	--
358	7.7	--	7.3	--	7.7	--	--	--	8.1	--
Sum	141.2	2.5	153.1	2.5	159.9	3.2	136.1	3.3	173.7	3.1
Average	4.9		5.3		5.7		6.2		6.2	
Std dev	1.9		1.9		1.9		1.9		1.9	

fire (table 3). By 2005, only six saguaro on Transect 4.5 survived from the 1995 River fire. Based on remnants of burned saguaro found along Transect 4.5 immediately after the River fire, we determined that saguaro had an initial loss in height. They measured approximately 92 m in dead height compared with the 25 m of height of surviving saguaro. By 2005, the six remaining live saguaro had accumulated 6 m of additional height. After 10 years, about 80 m of remnant saguaro skeletons were no longer evident and had decomposed. Only 12 m of dead saguaro remained.

In the Vista View fire, saguaro final total live height (286 m) was less than initial cumulative live saguaro height (343 m). Wind toppled or blew tops off some damaged saguaro in the Vista View area. The cumulative height of dead saguaro at 1 and 5 years post-fire was similar, about 20 m.

Discussion

Our long-term post-fire study has followed individual saguaro for a decade. Some surviving saguaro cacti and associated plants still appear to be suffering adverse effects from fire, even after 10 years. Unlike other studies tracking saguaro longevity and growth, we focused on

fire-injured saguaro and associated vegetation in our observations. The desert thorn-shrub habitat had no recent documentation of fire effects on saguaro survival or mortality. Huge areas on the Tonto National Forest had recently burned when we initiated our study (Narog and others 1995). Subsequently, increasing public appreciation for desert vistas and early results from our study led to improved fire management. A change was made in policies at the national forest, state, and local levels that recognized the fire sensitivity of saguaro and its associated ecosystem (Hunt 1997; Narog and others 1999; Wilson and others 1995).

Short term saguaro mortality is only part of the story. After 10 years we discovered that saguaro were still dying from delayed effects of fire injury. Both short- and long-term saguaro mortality was higher in burned than in unburned areas of our study. Natural attrition in unburned sites was minimal; therefore, environmental anomalies and variable weather conditions would not account for the higher loss of saguaro or their reduced growth in burned areas. While saguaro showed long-term adverse effects from both low and high severity fires, they survived low fire severity better than high severity. Not all fire-injured saguaro died immediately after the fire (Narog and Wilson 2004): some persisted for longer periods of time, and others

Table 2—Ten year point-quarter data for Vista View fire burned Transects 1, 6 and 7 showing live and dead saguaro heights (m) measured between 1994 and 2003, Tonto National Forest, Arizona.

Saguaro	1994												1998												2003											
	Live				Dead				Live				Dead				Live				Dead				Live				Dead							
	T1*	T6*	T7*	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7						
64	12	44	1.9	2.6	6.0	--	--	--	2.6	6.2	6.2	--	--	--	3.7	3.2	6.4	--	--	--	3.7	3.2	6.4	--	--	--	3.7	3.2	6.4							
11	32	83	6.5	4.0	3.3	--	--	--	6.5	5.8	3.3	--	--	--	3.2	4.6	3.8	--	--	--	3.2	4.6	3.8	--	--	--	3.2	4.6	3.8							
14	34	73	7.5	1.3	2.4	--	--	--	6.5	1.6	2.5	--	--	--	8.0	2.0	2.8	--	--	--	8.0	2.0	2.8	--	--	--	8.0	2.0	2.8							
44	41	11	5.5	6.3	3.1	--	--	--	6.2	6.1	3.5	--	--	--	6.4	3.6	4.0	--	--	--	6.4	3.6	4.0	--	--	--	6.4	3.6	4.0							
71	43	12	3.6	5.0	1.6	--	--	--	4.5	6.0	1.7	--	--	--	6.8	5.2	2.1	--	--	--	6.8	5.2	2.1	--	--	--	6.8	5.2	2.1							
13	52	13	8.5	5.0	5.8	--	--	--	7.0	5.2	7.3	--	--	--	8.0	6.4	8.0	--	--	--	8.0	6.4	8.0	--	--	--	8.0	6.4	8.0							
41	53	14	5.5	9.0	4.1	--	--	--	6.2	9.5	4.8	--	--	--	7.4	6.4	3.4	--	--	--	7.4	6.4	3.4	--	--	--	7.4	6.4	3.4							
51	61	22	8.5	1.4	8.0	--	--	--	8.5	1.4	7.5	--	--	--	8.7	1.4	6.2	--	--	--	8.7	1.4	6.2	--	--	--	8.7	1.4	6.2							
61	64	24	1.2	2.0	2.3	--	--	--	1.6	2.2	2.3	--	--	--	2.0	2.3	2.6	--	--	--	2.0	2.3	2.6	--	--	--	2.0	2.3	2.6							
12	71	34	8.0	2.3	4.0	--	--	--	7.2	2.5	4.2	--	--	--	8.3	3.1	5.7	--	--	--	8.3	3.1	5.7	--	--	--	8.3	3.1	5.7							
23	72	41	3.5	3.0	7.0	--	--	--	3.9	3.3	7.2	--	--	--	4.3	3.6	4.8	--	--	--	4.3	3.6	4.8	--	--	--	4.3	3.6	4.8							
24	73	51	4.5	3.8	4.2	--	--	--	5.1	4.0	4.3	--	--	--	5.7	4.6	5.4	--	--	--	5.7	4.6	5.4	--	--	--	5.7	4.6	5.4							
31	81	62	4.5	3.5	5.0	--	--	--	4.7	3.5	5.3	--	--	--	4.9	5.5	5.7	--	--	--	4.9	5.5	5.7	--	--	--	4.9	5.5	5.7							
33	22	63	4.5	5.5	5.9	--	--	--	5.1	6.9	5.8	--	--	--	6.6	--	--	--	--	--	6.6	--	--	--	--	--	6.6	--	--							
42	44	71	6.0	8.5	2.5	--	--	--	7.4	8.3	2.9	--	--	--	7.9	--	--	--	--	--	7.9	--	--	--	--	--	7.9	--	--							
52	51	72	6.5	8.5	8.0	--	--	--	7.1	5.9	8.0	--	--	--	7.8	--	--	--	--	--	7.8	--	--	--	--	--	7.8	--	--							
53	54	74	4.5	2.5	2.9	--	--	--	6.6	--	3.0	--	--	--	5.1	--	--	--	--	--	5.1	--	--	--	--	--	5.1	--	--							
54	11	81	6.5	--	4.0	--	2.5	--	7.2	--	4.2	--	2.3	--	7.5	--	4.8	--	3.9	--	7.5	--	4.8	--	3.9	--	7.5	--	4.8							
73	13	84	6.0	--	3.0	--	1.3	--	6.2	--	3.1	--	1.1	--	7.2	--	3.0	--	9.4	--	7.2	--	3.0	--	9.4	--	7.2	--	3.0							
81	14	31	7.0	--	5.3	--	0.5	--	5.2	--	5.5	--	0.5	--	8.9	--	--	--	2.5	--	8.9	--	--	--	2.5	--	8.9	--	--							
83	21	61	6.0	--	8.5	--	2.0	--	5.3	--	9.0	--	1.9	--	6.8	--	--	--	5.4	--	6.8	--	--	--	5.4	--	6.8	--	--							
84	23	33	4.3	--	6.5	--	0.8	--	3.6	--	6.4	--	0.4	--	5.4	--	--	--	2.5	--	5.4	--	--	--	2.5	--	5.4	--	--							
82	31	52	4.0	--	7.8	--	2.0	--	6.3	--	7.8	--	2.0	--	5.6	--	--	--	2.0	--	5.6	--	--	--	2.0	--	5.6	--	--							
34	82	53	3.1	--	13.0	--	0.5	--	3.6	--	13.0	--	0.6	--	4.1	--	--	--	12.5	--	4.1	--	--	--	12.5	--	4.1	--	--							
62	84	64	4.3	--	5.3	--	0.2	--	4.5	--	7.0	--	0.1	--	--	--	--	--	0.7	--	--	--	--	--	0.7	--	--	--	--							
22	83	21	2.5	--	4.8	--	1.5	--	2.5	--	--	--	0.7	--	--	--	--	--	0.9	--	--	--	--	--	0.9	--	--	--	--							
62	74	54	0.5	--	--	--	2.6	--	--	--	--	--	3.0	--	--	--	--	--	0.4	--	--	--	--	--	0.4	--	--	--	--							
21	--	--	--	--	--	--	1.5	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--							
32	--	--	--	--	--	--	1.5	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--							
Sum			134.9	74.1	134.2	4.1	11.6	5.0	141.1	74.8	135.8	4.7	9.0	6.2	150.3	51.9	83.7	4.8	60.2	40.8	150.3	51.9	83.7	4.8	60.2	40.8	150.3	51.9	83.7							
Average			5.0	4.4	5.2	2.1	1.2	5.0	5.4	4.7	5.4	1.6	1.0	3.1	6.3	4.0	4.4	1.6	5.0	6.8	6.3	4.0	4.4	1.6	5.0	6.8	6.3	4.0	4.4							
Std dev			2.1	2.5	2.5	0.8	0.8	0.0	1.7	2.4	2.6	1.3	0.8	3.4	1.9	1.6	1.5	1.7	3.6	2.1	1.9	1.6	1.5	1.7	3.6	2.1	1.9	1.6	1.5							

*Transect 1: N = 29; Transect 6: N = 27; Transect 7: N = 27. Total N = 83.

Table 3—Ten year point-quarter data for River Fire burned Transects 3 and 4.5 showing live and dead saguaro heights (m) measured between 1997 and 2005, Tonto National Forest, Arizona (N = 26).

Saguaro	1997						2000				2005			
	Live		Dead		Live		Dead		Live		Dead			
	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5		
34	2	4.1	5.8	--	--	4.6	6.5	--	--	5.3	6.7	--	--	
38	3	1.8	4.5	--	--	2.2	5.2	--	--	2.8	5.6	--	--	
39	5	6.8	4.0	--	--	7.2	4.4	--	--	7.9	5.1	--	--	
43	21	4.0	2.3	--	--	4.4	3	--	--	4.7	3.5	--	--	
44	28	6.2	4.5	--	--	6.3	5.2	--	--	6.5	6.0	--	--	
45	32	7.4	3.9	--	--	7.5	4.2	--	--	7.8	4.5	--	--	
46	1	6.3	3.2	--	--	6.8	3.4	--	--	7.1	--	--	0.8	
47	11	4.4	6.2	--	--	5.1	6.5	--	--	5.8	--	--	2.0	
48	7	6.0	3.7	--	--	5.2	--	--	1.7	6.6	--	--	1.5	
49	10	4.4	3.9	--	--	5.1	--	--	1.1	5.8	--	--	1.2	
52	17	3.8	4.6	--	--	4.1	--	--	--	4.8	--	--	1.2	
54	22	9.8	4.2	--	--	10	--	--	1.5	10.2	--	--	1.5	
55	9	8.0	3.3	--	--	8.4	--	--	1.5	8.8	--	--	--	
56	13	5.2	8.3	--	--	5.3	--	--	4.1	5.9	--	--	--	
57	16	2.3	8.3	--	--	2.4	--	--	3.5	2.8	--	--	--	
59	24	3.4	7.5	--	--	3.5	--	--	7.5	3.8	--	--	--	
62	4	5.5	--	--	2.4	5.9	--	--	2.3	6.5	--	--	2.3	
64	8	5.5	--	--	1.7	5.9	--	--	1.6	6.4	--	--	1.6	
63	12	5.0	--	--	0.6	--	--	1.5	0.6	--	--	1.5	--	
51	25	--	--	0.6	2.9	--	--	0.6	2.7	--	--	--	--	
60	26	--	--	0.4	4.1	--	--	0.4	2.9	--	--	--	--	
40	15	--	--	1.5	3.9	--	--	--	--	--	--	--	--	
41	20	--	--	0.3	0	--	--	--	--	--	--	--	--	
	23	--	--	--	2.4	--	--	--	--	--	--	--	--	
	27	--	--	--	1.9	--	--	--	--	--	--	--	--	
	29	--	--	--	4.6	--	--	--	--	--	--	--	--	
Sum		99.9	78.2	6.4	24.5	99.9	38.4	2.5	31.0	109.5	31.4	1.5	12.1	
Average		5.3	4.9	1.6	2.5	5.6	4.8	0.8	2.6	6.1	5.2	1.5	1.5	
Std dev		2.0	1.8	1.7	1.4	2.0	0.2	0.6	2	1.9	1.1	0.5	0.5	

Table 4—Percent mortality among all saguaro plots unburned and burned after the River and Vista View wildfires, Tonto National Forest, Arizona. Note: Six unburned saguaro are from Transect (T) 3.

Transect	Live	Dead	% Dead
Unburned			
T2 & T3	28	2	7
Burned			
River T3	18	5	22
River T4.5	6	20	77
Vista View T1	24	5	17
Vista View T6	13	14	52
Vista View T7	19	8	30
Sum	80	52	
Average			39

ultimately perished. Our data show that 5 years after fire was not sufficient time to evaluate the impact of fire on the growth increments in fire-damaged plants or the ultimate fate of individuals from the burned saguaro populations. We hope to reassess the saguaro in this study at 20 years post-fire to determine whether further mortality has occurred and to see if height growth trends have changed since our last measurements.

Our results showed a loss and decomposition of nearly 80% of a healthy pre-burn saguaro population on one transect during the first 10 years following a wildfire. Narog and Wilson (2005) documented persistent loss of associated vegetation that can serve as nurse plants in all the burned areas on our study sites 10 years after the fires.

Turner and others (1966) found poor saguaro seedling establishment and survival when appropriate environmental conditions and nurse plants are lacking. Proactive restoration efforts for burned saguaro ecosystems may be needed particularly after high severity or short-interval repeated fire. Maintaining strict fire prevention and suppression measures in high value saguaro habitat may be necessary to ensure that expansive vistas continue to include these iconic cacti.

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Post-Wildfire Erosion in the Chiricahua Mountains

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Abstract—The Horseshoe 2 Fire burned 90,226 ha (222,954 ac) of the Chiricahua Mountains in the Coronado National Forest of southeast Arizona from May 8 to June 25, 2011. This mountain range in the Madrean Archipelago was burned by widespread fires prior to 1890, numerous small fires after 1890, and, more recently, the 11,129 ha (27,500 ac) Rattlesnake Fire in 1994. The latter fire resulted in significant erosion during post-fire monsoon storms that eroded deep gullies (~10 m) in Ward Canyon (upper West Turkey Creek). Post-fire runoff deposited large amounts of sediment in lower channels, particularly in Rucker Creek and in Rucker Lake. The Horseshoe 2 Fire burned approximately 70% of the mountain range with a mosaic of fire severities. Post-fire erosion from floods and debris flows produced additional erosion and sedimentation that is currently being evaluated through fieldwork and repeat aerial photography. This paper discusses ongoing work regarding post-fire erosion and the impacts on channel systems in the Chiricahua Mountains.

Introduction

Record-setting wildfires burned across Arizona in 2011. The human-caused Horseshoe 2 Fire burned 11,110 ha (222,954 acres) of the Chiricahua Mountains between May 8th and June 25th, 2011, on the Coronado National Forest (CNF) (<http://inciweb.org/incident/2225/>). This fire burned approximately 70% of the mountain range (fig. 1) and currently stands as the 4th largest wildfire in state history (Southwest Coordination Center: <http://gacc.nifc.gov/swcc/predictive/intelligence/intelligence.htm>). Monsoon rains often follow immediately after the wildfire season and are often how fires are ultimately extinguished. Short-duration, intense bursts of rainfall from relatively common (<2-5 year frequency) storms can generate large floods and debris flows in watersheds disturbed by wildfires (DeBano and others 1998; Jenkins, 2011; Neary and others 2005). U.S. Forest Service (USFS) Burned Area Emergency Response (BAER) assessments were completed for the burned area. The soil burn severity map shows 12% of the Horseshoe 2 Fire burned at high severity and 30% at moderate severity (fig. 1). The BAER team conducted a hydrologic analysis of post-burn conditions using a 5-year return interval storm with an intensity of 12.5 mm/hr (0.5 in/hr), and a geologic analysis using burn severity, basin morphometrics, and soil characteristics to assess the potential for post-fire debris flows. These analyses indicated that post-fire peak discharges might increase from 2-15 times pre-fire conditions, and several watersheds had a high potential for debris flows (USDA Forest Service 2011).

Moody and Martin (2009) compared post-fire sediment yields across the western United States with 30-minute rainfall intensity from 10 rainfall regimes. They found that generally channels contributed ~75% of the post-fire sediment yield while hillslopes contributed ~25%, although most of the runoff came from hillslopes (Moody and Martin 2009). Understanding the sources of sediment from burned areas is important for assessing post-fire geomorphic responses of basins and the effectiveness of post-fire mitigation measures, both of which inform resource management decisions (Robichaud and others 2000). To understand sediment sources, baseline conditions must be established. Due to the short window of opportunity in Arizona between fire containment and the first monsoon storms, these data can be difficult to acquire. This study established post-fire, pre-storm conditions using aerial photographs flown immediately after the fire. Channel and hillslope conditions were monitored through the summer to document basin responses to significant rainfall. The objectives of this study are to monitor, document, and quantify post-fire erosion from channels and hillslopes, on a broad scale, in the Chiricahua Mountains following an approach used after the 2010 Schultz Fire in northern Arizona (Youberg and others 2011). The goals of this study are to document burned basin responses (floods vs debris flows) to significant rainfall, and the locations of post-fire erosion (channels vs hillslopes) to understand how post-fire erosion and deposition change over time, and how those changes influence post-fire flooding and sedimentation or recovery. The objectives of this paper are to report on the current status of the project and to discuss some of the basin responses from rainfall during the 2011 monsoon.

Background

Following the 2010 Schultz Fire near Flagstaff, Arizona, debris-flow and flood deposits were identified and mapped to assess basin response to rainfall. Limited channel measurements were collected, including an evaluation of available sediment in one small sub-basin following the 2010 monsoon (Carroll 2011), and a single series of

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

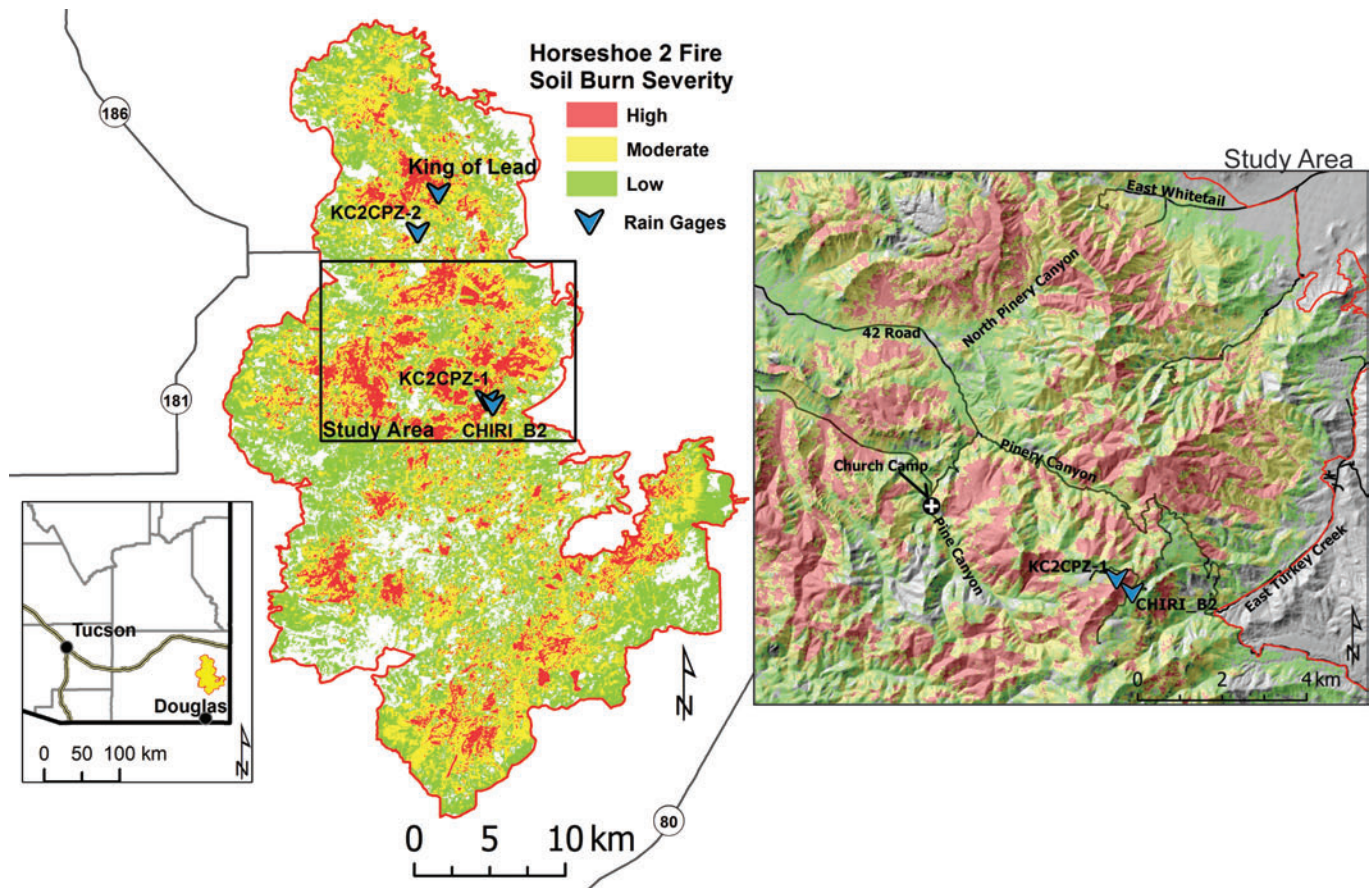


Figure 1—Location map of the Horseshoe 2 Fire with burn severity. Lower left inset panel shows the location of the Horseshoe 2 Fire in southeastern Arizona. The map of the fire shows soil burn severity map, location of rain gages, and study area outlined in box. The right image shows the study area.

cross-section surveys used to estimate peak flows from a productive runoff event across the burn area (Koestner and others, in press). No hillslope measurements were taken. Thus, to assess post-fire erosion following the Schultz Fire, aerial photography (scale 1:12 k) was flown after monsoon to capture initial post-fire erosion. The aerial imagery provided both a visual record of erosion and a means to create high-resolution (15 cm - 1 m) digital elevation models (DEMs) from the digital data using photogrammetric analysis. This method is also being utilized on the Horseshoe 2 Fire to monitor and assess post-fire erosion via a collaborative effort between the CNF, the U.S. Forest Service Southwestern Regional Office (RO), the Rocky Mountain Research Station, and the Arizona Geological Survey.

Extensive erosion following the Horseshoe 2 Fire was anticipated, given severe erosion previously observed after the 1994 Rattlesnake Fire. Tree-ring data show that the Chiricahua Mountains were burned by widespread fires prior to 1890 and numerous small fires after 1890 (Swetnam 2005). Due to fire suppression and livestock grazing, the fire regime changed during the 20th century (Swetnam 2005). The 1994 Rattlesnake Fire, which burned ~11,110 ha (27,500 ac) along the crest of the range (MTBS 2012), is considered one of the earliest large fires of the current fire regime. Approximately 21% of the total area was burned at high severity and 12% at moderate severity (CNF files). The monsoon rains following the 1994 Rattlesnake Fire caused significant post-fire erosion. Rucker Lake, at the south end of the range, had high sediment input prior to the fire and required frequent dredging to keep the lake open (Lefevre and Neary 1999).

During a post-fire monsoon storm multiple debris flows initiated in upper Rucker Canyon, and coarse sediment filled Rucker Lake. This event was unprecedented, delivering approximately three times the pre-fire sediment load to Rucker Lake (Lefevre and Neary 1999). Some of the most impressive erosion occurred in upper Ward Canyon on the steep western flank of Chiricahua Peak, where a 10-m gully formed. By 2004, the gully bottom had filled in approximately 4-5 m and widened 2-3 m through mass wasting processes (P. Pearthree, personal communication).

Study Area

The study area was selected using several criteria including burn severity, accessibility, proximity to communities, and the potential for significant post-fire erosion. The study area encompasses several canyons in the northern part of the burn area including Pinery, North Pinery, Pine and East Whitetail Canyons, and East Turkey Creek (fig. 1). Pinery Canyon and East Turkey Creek are dissected by the 42 Road, the only major east-west road through the mountain range, and East Turkey Creek contains the small community of Paradise. North Pinery and East Whitetail both have extensive areas of high burn severity (>~70%), and East Whitetail also contains a small community. Pine Canyon was partially burned in the Rattlesnake Fire with significant post-fire erosion. A church camp is also located within Pine Canyon and extensive patches on the steep northern slopes above the camp and in the upper canyon were burned at high severity.

Methods

Aerial Photography

The CNF with assistance from the RO GIS/Photogrammetry Program had aerial photography flown in the northern portion of the fire with the goal of capturing post-fire, pre-storm conditions of the study watersheds. The air photos were flown on July 1, 8, 14 and 15 at a scale of 1:12000. In addition to these photos, the RO collected aerial photographs in August and September as part of their ~5-year cyclical resource aerial photography program. These resource photos are digital with a resolution of 25 cm (10 in).

Precipitation Data

The first rain gage (CHIRI_B2) within the burned area was installed on the east side of Buena Vista Peak, near the 42D road, on July 1 by the University of Arizona/Biosphere 2. A temporary weather station with a recording gage (KC2CPZ-1) was installed on July 26 on top of Buena Vista Peak at the Barfoot Lookout location by the National Weather Service (NWS). A second temporary weather station (KC-2CPZ -2) outside our study area was installed by the NWS within Chiricahua National Monument on August 3. Two permanent ALERT gages were installed by the Arizona Department of Water Resources (ADWR) on August 26. One is co-located on top of Buena Vista Peak and will remain after the temporary weather station is removed. The second (King of Lead) is at the headwaters of East Whitetail Canyon, also outside of our study area near the King of Lead mine. In October, the USGS installed a stream warning system and a rain gage in Chiricahua National Monument.

Field Monitoring and Other Data

Visits to key study areas were conducted as soon as possible following significant storm events during the monsoon of 2011. Smaller storms were monitored remotely and basin responses determined from reports, videos and photographs taken by BAER Implementation team members, local residents and district personnel. Field visits covered as much of the study area as possible, focusing on those areas that had received significant rainfall, to document and photograph hillslope erosion and channel condition. Channel deposits were classified, when possible, as either flood flow or debris flow. In Pinery Canyon tributary, channel material was deposited on the 42 road, providing very good exposures of deposits for flow-type classification. In East Turkey Creek, however, the channels above the road have fairly deep basins. Often during field visits these deposits were either entirely buried leaving no cross-sectional exposures to characterize deposits or, more likely, the road crew had already cleared the road and cleaned out the basins leaving no undisturbed deposits to evaluate. Numerous photos and reports from these locations during the largest storms provide some information regarding basin responses.

Results

The first few rains that fell on the study watersheds were of moderate intensity and duration. They moved some sediment and ash in and through the channels, resulting mainly in nuisance flooding. Hillslope rilling was noted in the study area following a June 29 storm. The first major rainfall occurred on July 11 (fig. 2). The CHIRI rain gage recorded 54.4 mm (2.14 in) in 1 hour, 38 minutes, with a peak 30-minute intensity of 35.6 mm (1.4 in) (Steve DeLong, unpublished

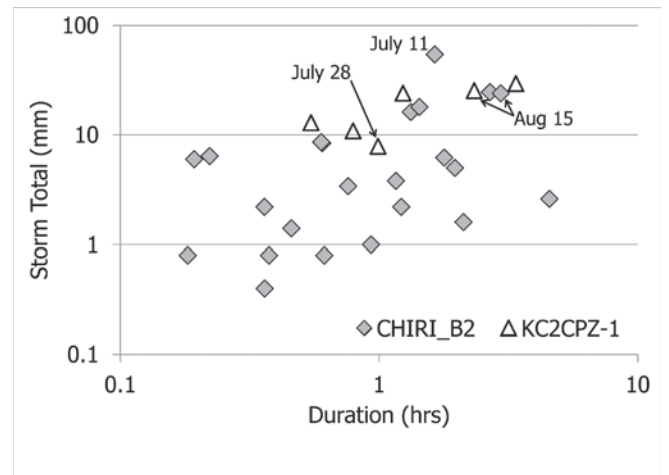


Figure 2—Rainfall storm totals with dates of debris-flow producing storms. The University of Arizona's rain gage, CHIRI_B2, was installed on July 1st and is located along the 42D Road. The NWS weather station, KC2CPZ-1, is located on top of Buena Vista Peak and was installed on July 26th.

data). The online NOAA Atlas 14 (<http://dipper.nws.noaa.gov/hdsc/pfds/>) classifies this 30-minute intensity as a 2- to 5-year frequency storm. On the east side of the range, where the rain gage sits, floods were observed in the East Turkey Creek drainage. On the west side of the range, debris flows occurred in several tributaries of Pinery Canyon, depositing debris on the 42 Road, and in tributaries to Pine Canyon above the church camp. Numerous storms throughout the summer produced large enough floods to generate documentation via reports, photos and videos. Additional debris-flow producing storms occurred on July 28, with a debris flow noted in a tributary to East Whitetail Canyon, and on August 15 with evidence of debris flows in Pine Canyon and East Turkey Creek (fig. 2). This storm significantly impacted the church camp with debris flows depositing just upstream and flooding throughout the camp. No debris flows were observed in North Pinery Canyon. Some landslides had been observed in this canyon during the BAER assessment (Youberg 2011) but no additional movement was noted over the monitoring period.

The aerial photographs flown in July to capture post-fire, pre-storm watershed conditions were actually flown over 4 days. The east side of the area was flown on July 1 and 8, prior to any significant rainfall, and the west side was flown on July 14 and 15 following the first debris-flow producing storm. There is a slight overlap in two flight lines along the ridge crest that captures the post-fire, pre-storm condition and the watershed condition after the first major storm. This is particularly evident at the top of Pine Canyon in an area that had been burned by the Rattlesnake Fire. The pre-fire imagery shows limited vegetation with large areas of grass cover. The soil burn severity map shows low to moderate burn severity in this area, while the vegetation burn-severity shows high burn severity. The removal of vegetation and the intensity of the rainfall were sufficient to cause dense rilling and to re-incise gullies that had begun to fill in after the post-Rattlesnake Fire erosion.

Discussion and Ongoing Work

During the summer of 2011 basin responses to rainfall were documented for five canyons burned by the Horseshoe 2 Fire. Debris flows occurred in Pinery and Pine Canyons on July 11, in East Whitetail

on July 26, and in East Turkey Creek and Pine Canyon on August 15. Channels affected by debris flows are being significantly altered as pulses of sediment are transported downstream with subsequent flows. As a result, channel cross-section areas are changing with each flow event. All other storms throughout the summer produced flood flows. Hillslope rilling, however, began with the first few minor storms in areas of high soil burn severity. Subsequent, more intense rains contributed to additional rilling and erosion.

A review of the channel conditions in Rucker, Ward and upper Pine Canyons show channels and hillslopes that had not recovered by 2011. In the upper canyons, prior to the summer storms, oversteepened channel banks of gullies had laid back and the bottoms had started to fill in (fig. 3). Following the summer storms, however, evidence of re-incised gullies and new hillslope rills and gullies are present in all of these canyons (fig. 3). In lower Rucker Canyon the post-Rattlesnake gravel/cobble channel bed had re-established a low-flow channel in some areas but not in others. As new sediment moves through the system these low-flow channels will once again fill with coarse sediment. Long-term disturbances such as these should be expected in canyons burned at moderate to high burn severity by the Horseshoe 2 Fire.

It was difficult to assess rainfall intensity associated with different flow events throughout the study area. There were only two gauges for the first half of the summer and they were essentially co-located. Rainfall intensity can sometimes be assessed for larger areas by

comparing gage data with radar data. This has been done for the 2010 Schultz Fire and is being done for the 2011 Monument Fire in the Huachuca Mountains (Youberg, unpublished data). Unfortunately, the Chiricahua Mountains are far from the surrounding radar stations, consequently, the beam is too far above the top of the mountain and often does not reliably capture rainfall on the mountains. Thus, no definitive conclusions can be drawn regarding rainfall intensity and return frequency for any of the study basins except for the headwaters of Pinery Canyon and a few tributaries to East Turkey Creek, which contain the CHIRI_B2 and KC2CPZ-1 gages. The largest storm recorded during the summer had a 2- to 5-yr, 30-min return interval.

This project is ongoing as funding allows. Aerial photographs will again be flown for the study area prior to the 2012 monsoon. This imagery will capture the first full year of erosion with snapshots in the August/September timeframe when the resource photos were flown. DEMs have not yet been developed but coarse-scale mapping of the deposits has occurred. Although there are several limitations to this study, including detailed hillslope and channel measurements, results from this study will help provide a broad understanding of post-fire erosion in the Chiricahua Mountains. Data from other studies (Gibson and others this volume) will be combined with the aerial imagery data to provide a clearer picture of sediment sources. In the long-term, these data will help inform resource decisions regarding post-fire land management.

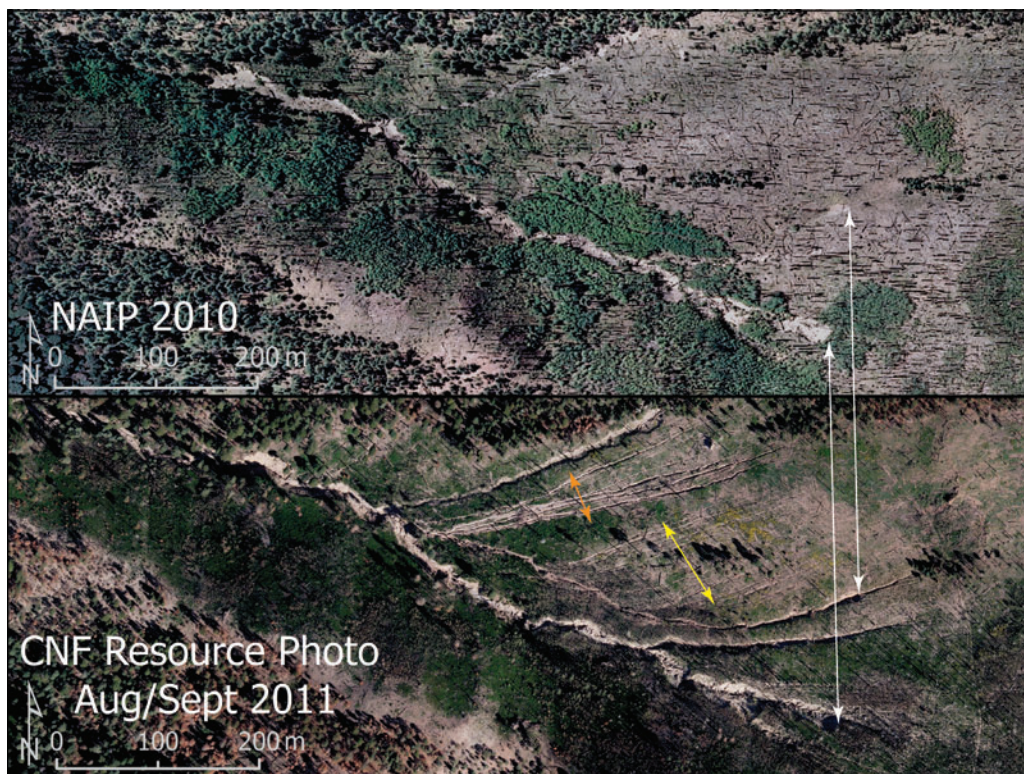


Figure 3—Ward Canyon in the headwaters of the West Turkey Creek drainage. The top photo is a NAIP 2010 image showing the post-Rattlesnake burned area and erosion. After the 1994 fire, post-fire runoff carved a ~10-m deep gully. By 2010 the gully banks had laid back and the gully was partially filled. Bottom photo was taken during late summer as part of the 2011 USFS resource photo acquisition program. This photo shows post-Horseshoe 2 Fire erosion from mid August storms with new rills (yellow arrow) and gullies (orange arrow), and re-incision and headward migration of previously existing gullies (white arrows).

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Tools for Management

Mapping and Assessing the Environmental Impacts of Border Tactical Infrastructure in the Sky Island Region

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Abstract—In this project we mapped the different types of border barriers, identified impacts of border infrastructure on public and private lands and conducted spatial analyses within the approximately 200 miles of international border in the Sky Island region. The Sky Island region, bisected by the U.S.-Mexico border, is critically important for its biodiversity and continental connectivity. Only on the Arizona side is the border lined with protected areas such as San Bernardino and Buenos Aires National Wildlife Refuges, San Pedro Riparian National Conservation Area, Coronado National Memorial, and several Wilderness Areas. In recent years the construction of border barriers, walls and other tactical infrastructure built to deter human and vehicle traffic across the border has had substantial impacts on ecological processes and created an impermeable boundary with effects that reach far beyond the footprint of the border wall. Due to the Department of Homeland Security's waiver of all legal requirements along significant portions of the U.S.-Mexico border, construction of border infrastructure proceeded without the requisite environmental impact studies or input from public land managers or private landowners. With the use of Geographic Information Systems we analyzed and graphically compiled results from over-flights along the border generating photographic data of the current state and effects of infrastructure, field visits to obtain complementary information and ground-truth aerial photographs, and observations of the direct effects of barriers to wildlife movements and the flow of ecological and hydrologic processes.

From a cartographic perspective, the United States-Mexico border is often depicted as a fairly straight line, drawn to differentiate the countries to the north and south. In ecological terms, the line is far from simple. Hundreds of miles of walls, fences, and other barriers have been installed that are impacting wildlife movement, watersheds, and ecosystem health and stability. In response to these construction projects, Sky Island Alliance took the lead in developing a geodatabase and map of the border in the Sky Island region as the first steps to understand the effects of infrastructure installation and to make this information available to the public.

On October 26, 2006, President George W. Bush signed into law the Secure Fence Act. The stated goals for this act included construction of hundreds of miles of additional fencing along our Southern border; authorization of additional vehicle barriers, checkpoints, and lighting to help prevent people from entering the United States illegally; and authorization for the Department of Homeland Security (DHS) to increase the use of advanced technology like cameras, satellites, and unmanned aerial vehicles to reinforce our infrastructure at the

border. Since the passage of the Act, the installation and maintenance of border tactical infrastructure (TI) has become a central component of DHS border activities (Whitehouse 2006).

In order to accomplish TI installation, the Department of Homeland Security (DHS) relied on provisions from earlier legislation known as the Real ID act of 2005, which gave DHS authority to waive all legal requirements for building border infrastructure, and proceeded with TI construction without having to go through an environmental impact analysis required by NEPA, the National Environmental Policy Act (Ganster 2007). While this has allowed for expedient wall construction along the US/Mexico border, it has created considerable concern among the public and in conservation communities over the short and long-term impacts on ecosystems, endangered and threatened species, wildlife corridors, and watersheds. As figure 1 highlights, approximately 200 miles of TI bisects the unique and fragile Sky Island bioregion. Sky Island Alliance (located in Tucson, Arizona) has been engaged in conservation advocacy of the border region since 1991. In 2010, Sky Island Alliance (SIA) photographed the extent of existing TI in the Sky Island region, and determined that a map detailing the types of barriers and other infrastructure was needed to understand real and potential threats to the area, as well as for conservation advocacy purposes. This project represents a culmination of those efforts. The map produced from this project will be published in print and online, and will be used as a tool for future conservation activities and advocacy. It is also the first comprehensive TI infrastructure map of the region available to the public.

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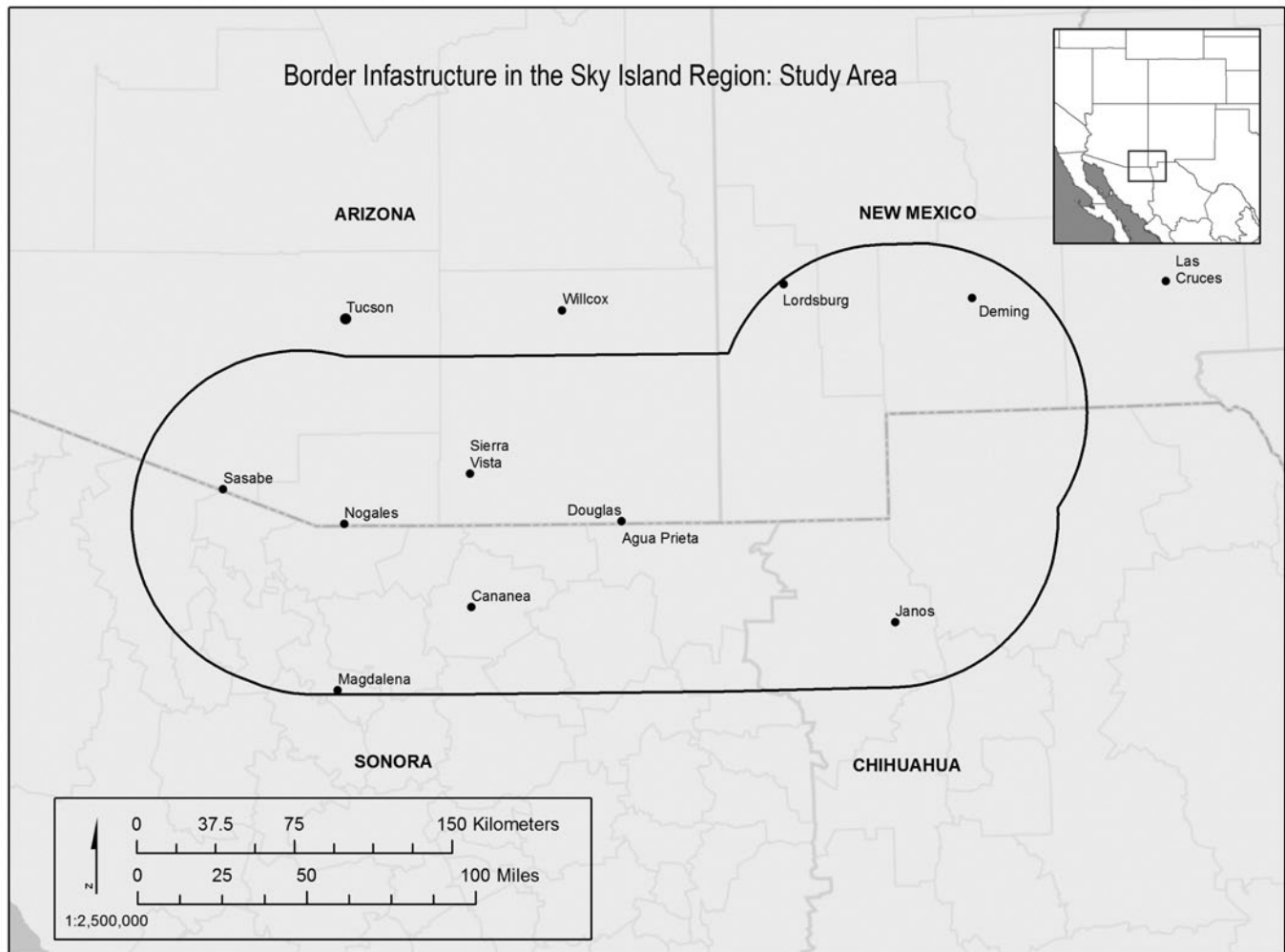


Figure 1—Project study area.

The Sky Islands: An Epicenter of Biodiversity

The Sky Island region of southeastern Arizona and southwestern New Mexico, and adjacent states in northwest Mexico (Sonora and Chihuahua), is characterized by forested mountains surrounded by intervening desert and grassland. This region hosts a high diversity of plants, animals and habitats. The region sits at the confluence of four major ecosystems: the Colorado Plateau, the Sierra Madre Occidental, and the Sonoran and Chihuahuan deserts. Because the region encompasses North America's two largest deserts and is a bridge between its two major mountain ranges, it is critically important to continental connectivity. Madrean pine-oak woodland, an important characteristic of Sky Islands, was designated a biological hotspot by Conservation International in 2005. The high number of federally protected areas along the international border—including national wildlife refuges, wilderness areas, national monuments, riparian national conservation areas, and national parks in Mexico and the United States—testify to the region's unique richness (SIA 2011).

Project Background

Creating a border infrastructure map per the needs of SIA required a multi-faceted process and an understanding of environmental and ecological factors of the region. In addition, we researched the political history of the area and how policy was developed to create the infrastructure, and the usage of land for wall construction, bridges, and easements. Because there was not a unifying source for these varied data needs, information was amassed from many sources, including printed publications, government websites, non-profit organizations including SIA, the Northern Jaguar Project and Defenders of Wildlife, border fly-over missions, and field collections. SIA began collecting data and monitoring the region in 2008, after the passage of the Real ID Act and the Secure Fence Act and the ensuing construction of the TI. Since then, it has used staff and volunteers to document wildlife corridors and monitor erosion and habitat degradation in the region as a result of construction and increased human activity.

In 2010, SIA conducted two photographic fly-over missions to capture the extent of the tactical infrastructure in the Sky Island region. The flights documented infrastructure from Sasabe, Arizona, to the eastern edge of New Mexico's "boot heel." The aircraft, equipped with

two photographers and a note-taker/navigator flew the extent of the region (approximately 200 miles) from west to east, on the south side of the border. The majority of the images were taken from the perspective of looking north, with images also captured from the southern side of the plane to assist in geo-referencing the photos based on the area's topography. As figure 2 shows, the photos from these flyovers provided an essential visual record of the extent of the TI. The note taker recorded on a topographic map the changes in the infrastructure that could be detected from the air. Although this process produced some excellent documentation of the border infrastructure, it took considerable time to geo-reference the photos to actual coordinates on the ground. This was accomplished by comparing the images to the topographic maps used during the flights and verifying the locations with Google Earth.

After compiling a profile of the TI through the aerial images, we realized that ground-truthing data collection would be needed to better understand the types of infrastructure used in areas that were either not clearly captured in imagery and/or in important conservation areas. In July and August of 2011 we visited several significant areas along the border, including the Buenos Aires National Wildlife Refuge (BANWR), the San Pedro Riparian National Conservation Area (SPRNCA), and the San Bernardino National Wildlife Refuge. As an example of the importance of these areas ecologically, the San Pedro is one of the last free flowing rivers in the desert southwest. It is also a global hotspot for bird and mammal diversity and is certainly one of the most significant wildlife corridors connecting the United States and Mexican nations. It is also important to note that the wall construction in the SPRNCA boundaries represents the first time such activities had occurred on public land that had been federally designated as a protected area (Segee and Cordova 2009).

Infrastructure Classifications

In the Sky Islands region, most of the existing TI falls into two main categories: pedestrian fencing and vehicle barriers. There are sub-categories with style/material differences within the two main categories. Table 1 outlines the different types of TI documented over the course of this project. Based on our observations, the construction goals for using different styles depended on topographical features of the area. For example, vehicle barriers were employed in certain riparian areas and other locations that the terrain presented challenges to constructing pedestrian barriers.

Cartography Goals

Once we had assembled our data, we began the task of creating a map that depicted the area and its relationship to the constructed tactical infrastructure. The goal for this map was to provide viewers a way of seeing this area as an ecological region that transcends political borders, and that the border infrastructure construction bisects the region and its important ecological processes. To accomplish this goal we did our best to downplay the state and national borders, focusing instead on the tactical infrastructure as the dividing line (fig. 3). We also made sure to include important wildlife preserves in Sonora and Chihuahua. Far too frequently, maps of the U.S./Mexico border only provide information on the northern side of the border. We did our best to rectify that approach with the information we had available.

Tactical Infrastructure Footprint

Once the data was compiled and assembled into a comprehensive map, it became possible to establish some baseline footprint data that can be used for conservation advocacy.



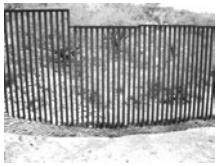




The infrastructure information compiled for this map yielded some interesting footprint statistics. Table 2 provides statistics on barrier miles in protected areas. In looking at these figures it is important to consider the following facts: (1) The mileage listed is an approximate based on GIS tools, aerial photography, and ground truthing efforts; and (2) construction is continuing on the border, and this data represents a snapshot of the situation as of July, 2011. In addition to the linear miles of federal land that the tactical infrastructure now occupies, hundreds, if not thousands, of acres of land has also been allocated and used by Custom and Border Protection (CBP) for infrastructure purposes under the auspices of the "Roosevelt Reservation." This little-known piece of legislation allows for a "public highway" to run along the U.S./Mexico border. CBP has used this to build access roads and other TI, and in several locations, have extended the easement well beyond the 60 feet to 120 feet or more. Environmental stewardship plans produced by CBP estimate a loss of 552 acres in vegetation communities from the barrier construction activities (Homeland Security 2008). Conservative estimates from this project place that figure at more than 900 acres in lost habitat, with over 500 acres on federal land.

Based on infrastructure measurements, the data collected during this project highlight the impact of the TI in federal areas. It is important to remember that this infrastructure, with an average construction cost of \$4.1 million per mile, was placed on U.S. federal land, in



Figure 2—Aerial view south to north of the San Pedro River area bisected by the international border (non-contiguous photos). On the Arizona side, the San Pedro is a riparian National Conservation Area. In addition to 6-ft high walls, a wide border road and numerous access roads fragment the land (left); Normandy-style vehicle barriers cross the San Pedro River bed (center); washes and arroyos are paved to protect the road, but water courses are blocked by pedestrian fences (right) (photos courtesy of Sky Island Alliance, Paul Condon, and LightHawk Inc.).

Table 1—Barrier classifications and characteristics (photos by Sergio Avila-Villegas and Caroline Patrick-Birdwell, 2011).

Barrier photo	Barrier type	Approximate height	Materials	Wildlife friendly	Water friendly
	Pedestrian/	15 to 18 feet	Steel, recycled helicopter landing mats	No	No
	Pedestrian/bollard	15 to 18 feet	grout-filled steel	No	No
	Pedestrian/bollard	15 to 18 feet	grout-filled steel	No	No
	Pedestrian/Water-drainage Gate	15-18 feet	grout-filled steel posts with gate housing	No	Variable; gates are only water friendly when lifted in advance of a storm event
	Pedestrian/mesh	15-18 feet	Steel with steel/wire mesh	No	No
	Vehicle/Normandy	4-6 feet	Non-reflective steel	Variable	Variable
	Vehicle/Post and Rail	4-5 feet	Non-reflective steel	Variable	Variable

highly sensitive ecological hot spots, without benefit of environmental analysis or environmental impact statements. The next phase for this project is to analyze the data more thoroughly and then use it to advocate for enlightened border security strategies that consider the environmental implications of those efforts.

Given the size and significance of the border section of the Sky Island bioregion, this project represents a starting point for further

research. With the infrastructure in place in 62% of the region’s international border, biologists are already seeing signs of interruptions in wildlife corridors as well as erosion and other damage to fragile riparian ecosystems. The map and data produced for this project are important first steps for understanding the threats of the border wall on the environmental health of the region.

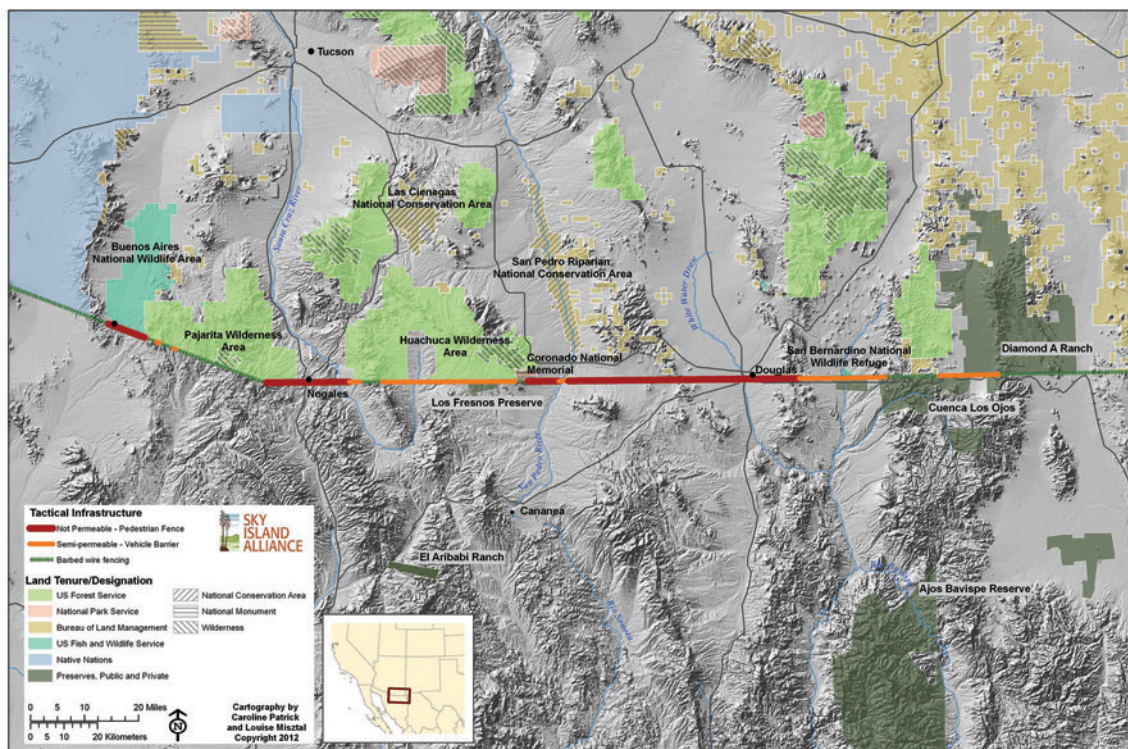


Figure 3—Infrastructure map (Cartography by Caroline Patrick-Birdwell and Louise Misztal, 2012).

Table 2—Tactical infrastructure mileage/area approximations.

	Vehicle barrier	Pedestrian barrier	Total border length	Percent covered w/barrier	Total barrier (study area)	Study area
Designated wilderness			4.18	0		
Wildlife refuges	3.06	5.44	8.5	100		
Conservation areas	1.43	0.3	1.75	100		
U.S. Forest Service	17.5	5.65	73	32		
National Park Service	0.25	1.8	3.5	58		
Other (public/private)	32.96	57.91				
Total (all land types)	55.2	71.1		62	126.3	203
Acres used in 60 ft. barrier corridors						
Federal land	516					
Total	918					
CBP predicted vegetation loss	552					

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Using Remote Sensing to Monitor Post-fire Watershed Recovery as a Tool for Management

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Abstract—Post-fire watershed recovery is influenced by numerous variables but one of the most important factors is the rate of re-establishment of vegetative cover. Burned Area Emergency Response (BAER) teams, along with other agencies (Natural Resource Conservation Service, state, counties, cities, etc.), prescribe temporary post-fire mitigation treatments based on expected post-fire responses of watersheds to fire-caused damage and based on threats to life, property, and resources associated with watershed damage. The objective of this project was to develop tools to more accurately assess the rate of vegetation regeneration after wildfire that will help managers decide if there is a continued need for mitigation measures. We develop a decision support tool to aid land managers and emergency response personnel in their evaluation of continued risks posed by recovering watersheds.

Introduction

In the last decade wildfires have increased in both size and severity (Westerling and others 2006; Snider and others 2007; Westerling and Bryant 2008). The effects of wildfires potentially impact property within and adjacent to burn areas several years post-fire via their adverse effects on watersheds (Jung and others 2009; Kinoshita and Hogue 2011). As a result, land managers are constantly seeking ways to assess post-fire watershed responses and their potential impacts (e.g., flooding, erosion, sedimentation) to federal and non-federal lands. After a significant wildfire, federal land managers restore and rehabilitate burn areas in three ways: suppression repair, emergency response (within 1-3 years after fire), and long-term rehabilitation (3-10 years after fire). Treatments implemented as part of Burned Area Emergency Response (BAER) are designed to reduce post-fire watershed impacts to life, property, and natural and cultural resources. These treatments, however, are viewed as temporary and are monitored, maintained or even retreated for up to three years after fire containment (U.S. Department of Agriculture Forest Service 2012).

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The type and duration of treatments in the aftermath of a fire is directly related to the degree of watershed impairment. A primary rehabilitation objective is restoration of vegetation cover to stabilize slopes and erodible soils, and reduce overland flow. Hillslope erosion is inversely related to plant cover and is considered minimal when plant cover is $\geq 60\%$ (Noble 1965; Orr 1970). For example, treatments such as straw mulching are most effective at reducing rill development and sediment transport when cover is $>60\%$ (Robichaud and others 2010). Cover is especially critical in the first year after the fire when the risk of erosion is highest (DeBano and others 1998).

Remote sensing and geospatial technologies are frequently used by land managers to guide resource management decisions. Moderate resolution satellite imagery, most notably Landsat, has proven to be a valuable information source for mapping fire severity and its effects on vegetation (Clark and Bobbe 2006) and monitoring post-fire vegetation recovery (Diaz-Delgado and others 1998; Clark and Kuyumjian 2006; Wittenberg and others 2007). Three well-known Landsat image derivatives used in fire effects mapping are the normalized difference vegetation index (NDVI) (Tucker 1979),

$$\text{NDVI} = (B4 - B3) / (B4 + B3),$$

the enhanced vegetation index (EVI) (Huete and others 2002),

$$\text{EVI} = 2.5 * ((B4 - B3) / (B4 + 6 * B3 - 7.5 * B1 + 1)),$$

and the normalized burn ratio (NBR) (López Garcia and Caselles 1991),

$$\text{NBR} = (B4 - B7) / (B4 + B7).$$

where B is the top of atmosphere (TOA) reflectance of the specified Landsat band. Vegetation indices are common remote sensing products that are used to highlight a particular vegetation property.

While both NDVI and EVI measure the photosynthetic activity and chlorophyll content in plants, the EVI was developed to correct for soil background signals as well as atmospheric influences (Huete and others 2002). The NBR is influenced by chlorophyll activity, but it is influenced more by moisture content of vegetation and soils (presence or absence of dry, bare soil and healthy vegetation) (Key and Benson 2006).

BAER teams, and those charged with long-term monitoring of watershed recovery, utilize these vegetation indices to ensure that stabilization plans remain on schedule. Since severely burned watersheds often require > 3 years (limit of BAER program's stewardship) to return to pre-fire conditions, managers need a method to monitor their condition (U.S. General Accounting Office 2003). Currently, however, managers lack a cost-effective way to evaluate watershed recovery that could help decide when to end temporary protective treatments. Thus, the objective of this project was to use remote sensing to monitor post-fire vegetation recovery and to develop a decision support tool that assists managers in their assessment of risks posed by the watershed to resource values.

Methods

The study area included six fires that burned between 2003 and 2010 and included a variety of elevations, soil burn severities, and stages of recovery (table 1, fig. 1). The six fires burned in predominately chaparral and mixed conifer cover types.

Data on percent vegetative cover were collected at several locations within the burn areas. We utilized pole-mast photography, that is, down-looking camera attached to the top of a telescoping monopod (fig. 2) to measure ground cover from heights ranging from 25-30 feet (Gilbert and others 2009; Smith and others 2000; Vanha-Majamaa and others 2000). Plots were chosen for ease of access, internal homogeneity, and soil burn severity. We took between four and ten photos per plot depending on the size of the homogeneous patch. Photos were spaced approximately 15 meters apart and interpreted with custom-built tools within Esri's ArcGIS ArcMap© using a random dot grid sampling of 600 points per plot. Plant cover was termed either present or absent at each point and cover was based only on living plants (both healthy and dormant/senesced vegetation). Plots were given a single percent cover value using the count of covered points.

A remote sensing data analysis was conducted to relate the photo-interpreted field plots to the maximum greenness observed from

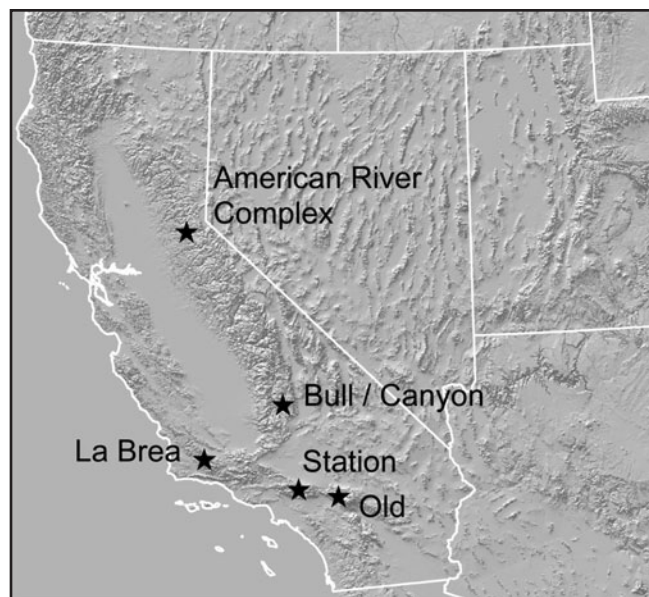


Figure 1—The six fires sampled (burn date) included Old (2003), American River Complex (2008), La Brea (2009), Station (2009), Bull (2010), and Canyon (2010).

satellite imagery during the growing season. To accomplish this, we compiled all available cloud-free Landsat imagery acquired for each growing season after the fire. For each Landsat image, we created an NDVI, EVI, and NBR vegetation index layer. The vegetation index data for each growing season were further analyzed on a per-pixel basis to derive maximum observed vegetation index value during the growing season (Sousa and others 2003). The annual maximum vegetation index value results capture the spatial and temporal distribution of annuals and other vegetation that green up in the spring and those whose peak green-up is later in the season.

Each plot intersected between 2 and 5 Landsat pixels depending on the plot size and orientation. The mean value of the annual maximum vegetation index pixels intersecting the plots were calculated for each year. We then performed regression analysis between ground cover derived from pole-mast photography and the mean vegetation index value computed from the three vegetation indices for each growing season.

Table 1—We analyzed vegetation recovery on 6 burned areas and applied our models to fires in the Madrean Archipelago.

Fire name	Year burned	Location	Acres	Elevation range	Soil burn severity percentages ^a	Project application ^b
Old	2003	San Bernardino, CA	91,281	2,000-7,600'	24, 20, 46, 10	Sample
American River Complex	2008	Foresthill, CA	20,541	2,500-6,700'	27, 35, 26, 12	Sample
La Brea	2009	Santa Maria, CA	89,489	1,100-5,000'	13, 24, 53, 10	Sample
Station	2009	La Cañada, CA	160,577	2,000-6,500'	12, 16, 62, 10	Sample
Bull	2010	Kernville, CA	16,442	2,700-7,400'	13, 37, 49, 1	Sample
Canyon	2010	Lake Isabella, CA	9,860	2,000-6,000'	18, 35, 43, 4	Sample
Monument	2011	Sierra Vista, AZ	32,837	4,400-9,500'	9, 42, 39, 10	Modeled
Horseshoe2	2011	Portal, AZ	222,694	4,500-9,800'	18, 42, 36, 4	Modeled

^a Percentage of area classified as unburned, low, moderate, and high as estimated from the Burned Area Reflectance Classification (BARC).

^b Field data was gathered on "sample" fires; models were applied to create predicted cover maps on the "modeled" fires.

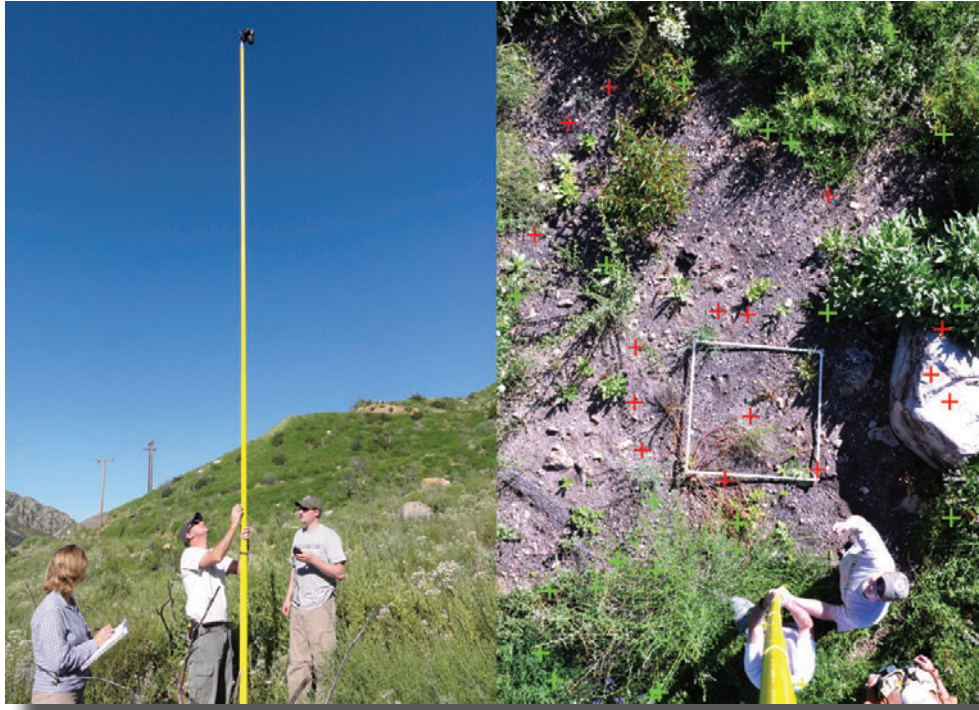


Figure 2—Field sampling included an innovative use of pole-mast photography. We took multiple photos in a homogeneous plot; percent ground cover was interpreted using a random dot grid overlaid on photos in Esri's ArcGIS ArcMap.

Results

Regression models produced an acceptable fit for NDVI ($N = 53$, $R^2 = 0.65$, $p = 0.038$) and EVI ($N = 53$, $R^2 = 0.63$, $p = 0.019$) but not for NBR ($N = 53$, $R^2 = 0.17$, $p = 0.004$). Fitting a simple linear model resulted in a “reasonably good” relationship between ground-observed cover and the NDVI index.

$$\text{Percent cover} = 221.18 * \text{MaxNDVI} - 26.273$$

The relationship between ground cover and EVI was best represented by a polynomial model (fig. 3).

$$\text{Percent cover} = -455.22 * \text{MaxEVI}^2 + 519.99 * \text{MaxEVI} - 47.508$$

Discussion

Despite the utility of NBR for burn severity mapping (Chen and others 2011), it did not correlate well with field-measured ground cover (fig. 3). The NBR is best suited for densely forested areas and, in general, does not perform as well in sparsely vegetated areas (Miller and Thode 2007). Our data show considerable confusion of NBR values in the 0–30% observed cover range (fig. 3). This confusion is probably due to the influence of Landsat band 7 in the NBR algorithm since similar results were not found in the NDVI or EVI correlations, neither of which use Landsat band 7. Conversely, the NDVI and EVI had significantly better correlations than NBR. These results have operational significance in providing user flexibility to apply multiple available remote sensing assets for post-fire recovery monitoring. Specifically, a limited number of satellite sensors collect data in the 2.1 μm band which is necessary for generating the

NBR. However, several moderate resolution sensors collect data in the visible/near infrared which is required for generating EVI/NDVI.

Initial results indicated correlations between EVI and NDVI with plant cover on the six different fires sampled. Nevertheless, we had to confine our sampling to chaparral and mixed conifer forests in California because of project timelines and budget constraints. There is an obvious need to continue testing in other vegetation types. Furthermore, we sampled each fire only once which created a single snapshot in time of the vegetation. To some extent we addressed this problem by leveraging annual time series satellite imagery and field photo interpretation that inventoried all living vegetation material (green and brown).

Additionally, the procedure and models developed through this initial effort can be enhanced by conducting field observations at permanent plots on a regular interval in the years following a fire. This supports multi-temporal assessments of post-fire vegetation conditions at intervals defined by land managers and facilitate the ability to assess and quantify rates of vegetation cover change. To this end, permanent plots have been established on the Bull and Canyon Fires (fig. 1), the two fires we sampled in this project, for long-term monitoring. As we obtain additional samples, we will improve the modeling to better correspond to observed ground cover.

There was one impediment to using pole-mast photography—interference by the overstory tree canopy. We found this technique did not work well in plots with a living overstory canopy (higher than 30 feet) that had little or no live understory. This situation resulted in high vegetation index values because the satellite sees the top of the living canopy but low cover values because the photo was captured beneath the canopy. This is not important when the overstory consists of burned snags because the understory ground cover is viewable by both the satellite and photography.

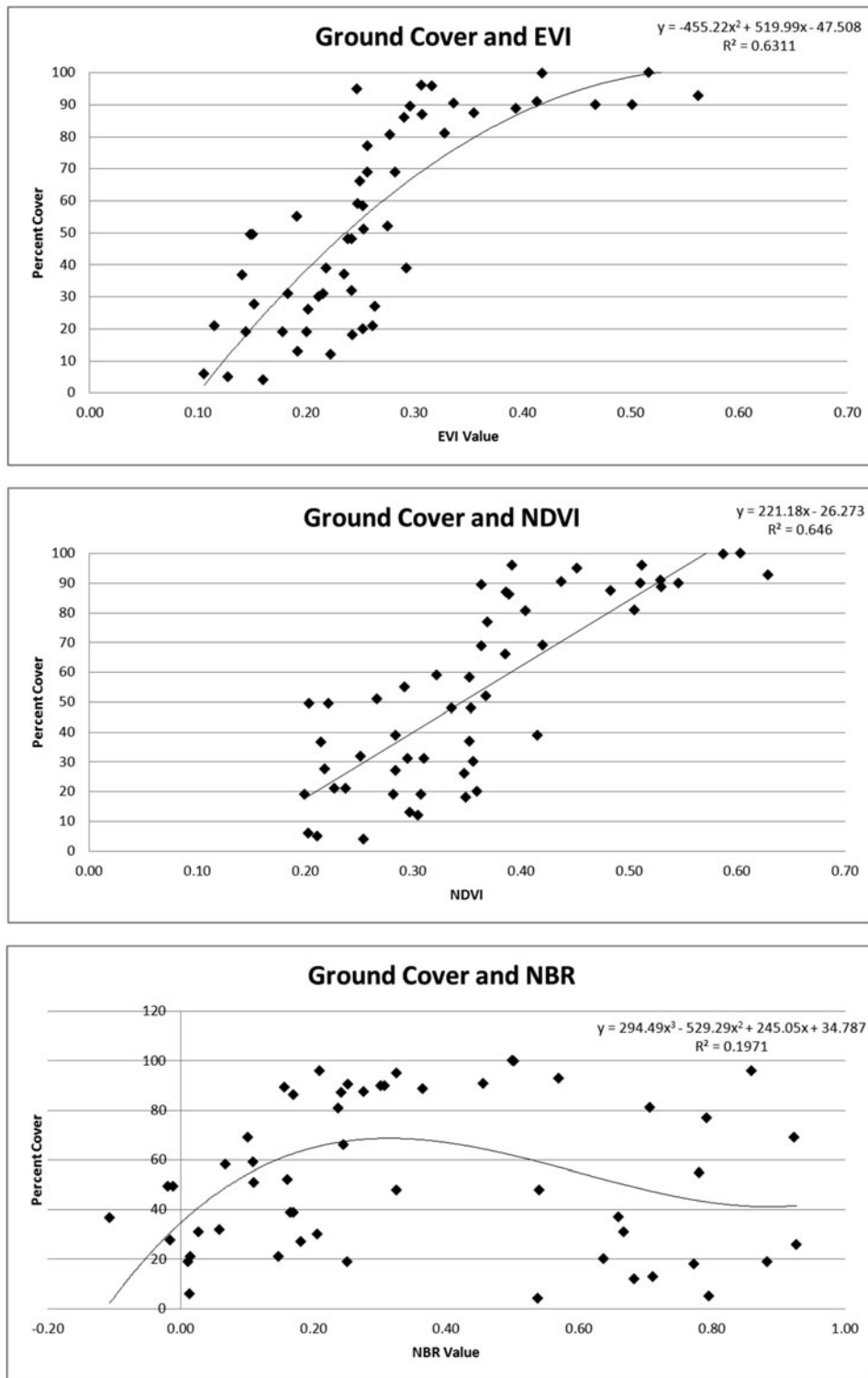


Figure 3—Both EVI and NDVI were well correlated with photo-interpreted ground cover although NBR performed poorly.

Application

To test our model, we applied it to the Monument and Horseshoe 2 Fires that burned in the Madrean Archipelago of Southern Arizona during 2011. We compiled maximum NDVI/EVI composite layers to create a continuous raster layer where every output pixel represents a predicted ground cover value. Broad classes of vegetation cover (e.g., 0-30%, 30-60%, 60-100%) were applied to the continuous data for easier interpretation (fig. 4). An initial validation of the classification for the Monument Fire was encouraging and it appeared to be a potentially useful layer for predicting ground cover in the semi-arid Southwest. Acquisition of field observation data for model validation and further assessment of this methodology is planned for other fires in the region. Also, class thresholds can be adjusted by managers based on their resource needs and to identify high risk areas.

Decision Support Tool

Results from the described methodology can be integrated into a larger decision support tool. The decision support process (fig. 5) is a new tool developed by combining the Fuels Treatment Planning Decision Support Process (2009, Fire Science Digest, JFSP, Issue 7), Forest Service Manual 2520 (2523.1), Calculated Risk: a Tool for Improving Design Decisions by Larry Schmidt (October, 1998 STREAM NOTES), and Assessing Post-Fire Values-At-Risk with a New Calculation Tool. This tool is intended to be used by managers to utilize satellite imagery (vegetation indices), to follow watershed recovery and evaluate potential impacts to values at risk identified during the BAER assessment.

The process described above utilizes composite satellite imagery to generate percent cover from NDVI values. By factoring in percent soil cover, soil depth, and type of vegetation cover, land managers

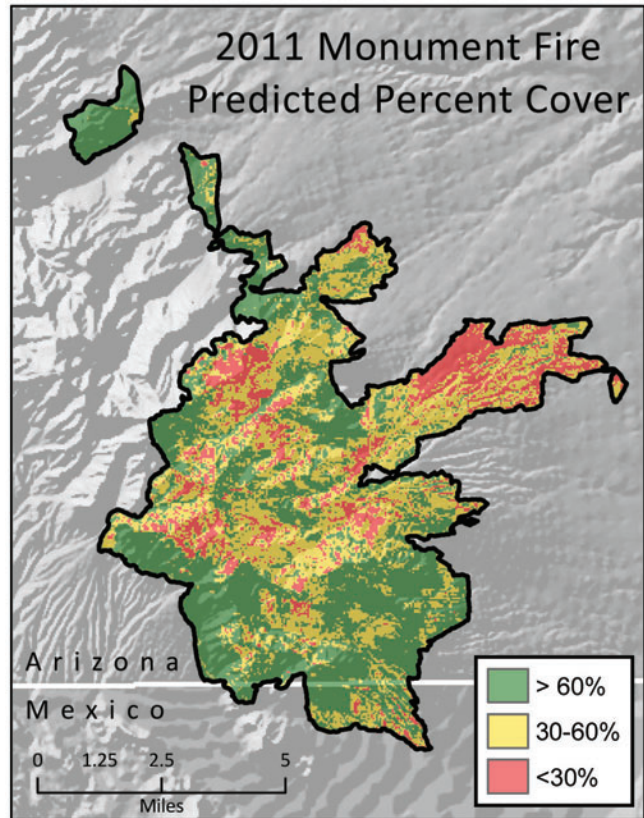


Figure 4—The Monument Fire burned near the town of Sierra Vista, Arizona, in June 2011. This map shows the predicted ground cover in three cover classes: 0-30% (red), 30-60% (yellow), and 60-100% (green).

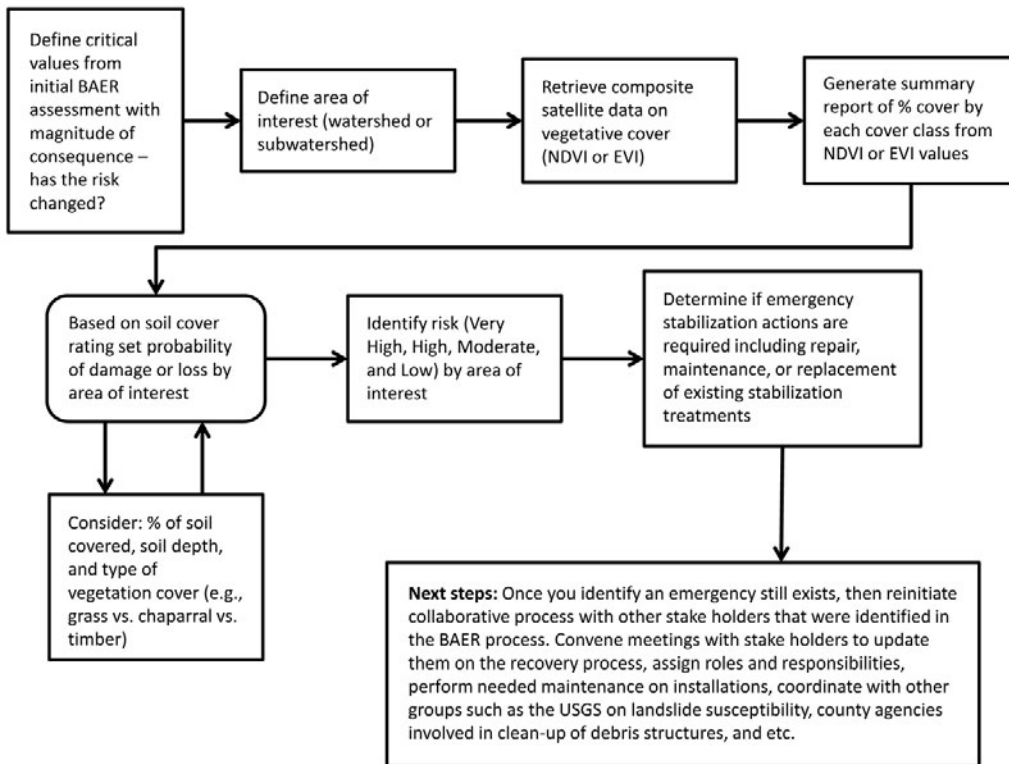


Figure 5—Flow chart for the decision support tool.

may identify potential risks at the watershed scale using departures from pre-fire conditions. Managers know that $\geq 60\%$ cover typically reduces the potential for rill development and hillslope erosion (Noble 1965; Orr 1970; Robichaud and others 2010). Therefore, if the watershed has recovered to $\geq 60\%$ cover, the associated risk of erosion in those areas drops to low or moderate, determinations which could trigger the removal of temporary protective treatments. If, however, the analysis shows $< 60\%$ cover then removal of treatments may increase the risk to high or very high. Determinations of high or very high might prompt management agencies to re-initiate a collaborative process with stake holders identified in the BAER process which might include the National Weather Service (NWS), government-based Offices of Emergency Services (OES), Natural Resources Conservation Service (NRCS), U.S. Geological Survey (USGS), local flood control districts, and private landowners.

Conclusions and Recommendations

Our model appears to predict the post-fire recovery of ground cover well. We believe the cover class maps can be used in concert with our developed decision support tool, on-the-ground observations, and good communication between cooperating agencies to help land managers make better informed decisions regarding existing protective treatments and burned watersheds upslope. The cover class maps and decision support tool proposed in this project represent a step toward a more efficient monitoring approach as well as provide a standard and repeatable protocol for managers throughout the nation. Finally, we plan to strengthen the model by applying it to other fires to test its robustness.

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Gila River Basin Native Fishes Conservation Program

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Abstract—The Gila River Basin Native Fishes Conservation Program was established to conserve native fishes and manage against nonnative fishes in response to several Endangered Species Act biological opinions between the Bureau of Reclamation and the U.S. Fish and Wildlife Service on Central Arizona Project (CAP) water transfers to the Gila River basin. Populations of some Gila River native fish species are rare in the wild and appear on the verge of extirpation. The CAP Program provides monies to undertake and support conservation actions for five priority fishes and other native fishes in the Gila River basin by implementing recovery plans. The Program will last 30 years, and provide more than \$16M. In addition, the Program provides monies to control and eradicate nonnative fishes and other non-indigenous aquatic organisms. Thus the Program is directed toward actions against nonnative aquatic biota where it interferes with recovery of native forms. Fund transfers from Reclamation to the Service began in 1997; about \$6.8M has been allocated so far and Reclamation will transfer about \$9.2M the next 17 years. One half of the funding is identified for native fish recovery actions, and one half for non-native aquatic biota control actions. Multiple conservation and recovery projects benefitting native fish in the Gila basin have been funded so far. In addition, barriers and management against nonnative species have been funded and completed.

Introduction

The Gila River Basin Native Fishes Conservation Program (GRBNFCP) is an outgrowth of reasonable and prudent alternatives (RPAs) developed by the U.S. Fish and Wildlife Service (Service) and U.S. Bureau of Reclamation (Reclamation) to prevent jeopardy to the continued existence of federally listed fishes resulting from operation of the Central Arizona Project (CAP). The RPAs were developed as part of a biological opinion (USFWS 1994) under the Endangered Species Act (ESA) section 7 consultation process (16 U.S.C. 1531 *et seq.*). The CAP is a Bureau of Reclamation constructed aqueduct that delivers water from the Colorado River to the Gila River basin in central and southern Arizona (fig. 1). Nonnative fishes and other aquatic organisms found in the Colorado River and elsewhere in the system can be transported via the CAP and released (actively or passively) into the Gila basin where they can negatively impact native fishes. The presence of nonnative fishes is now considered the primary obstacle to conservation and recovery of natives in the region through a myriad of effects including predation, competition, hybridization, and pathogen and disease transmission (Clarkson and others 2005; Hubbs 1955; Miller 1961; Minckley 1973, 1985; Minckley and Deacon 1991; Minckley and Marsh 2009; Moyle and others 1986; Williams and Sada 1985).

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It was determined infeasible to prevent nonnatives from entering and escaping the CAP, so the RPAs were crafted to limit and mitigate their upstream spread into streams occupied by listed fishes. They called for construction of fish barriers to prevent upstream movements of nonnatives, monitoring to detect the presence and distribution of nonnatives, and funding to implement recovery plans of native fishes and control nonnatives. An RPA was also developed to educate the public about the values of native fishes and the problems that nonnatives create for them. The GRBNFCP is funded by Reclamation and is directed by the Service and Reclamation, in cooperation with the Arizona (AZGFD) and New Mexico Game and Fish (NMDGF) departments.

Here we discuss the two funding RPAs: recovery of natives (RPA 3) and management against nonnatives (RPA 4). The Program mission is to undertake and support conservation actions (recovery and protection) for federal and state listed or candidate fish species native to the Gila River basin by implementing recovery plans for those fishes. The two native trouts are specifically excluded, as they are the focus of other recovery programs. A strategic plan (USFWS and others 2007) identifies the long-term vision for the Program as well as broad goals and actions that are expected to be accomplished during the current 5-year period (<http://www.usbr.gov/lc/phoenix/biology/azfish/pdf/5yearstraplan2008final.pdf>).

There are five priority-listed native threatened or endangered fish species in the GRBNFCP: Gila topminnow *Poeciliopsis occidentalis*, spikedace *Meda fulgida*, loach minnow *Tiaroga cobitis*, Gila chub *Gila intermedia*, and razorback sucker *Xyrauchen texanus*. Other listed or unlisted native fish in the Gila River basin are also eligible for conservation actions. In addition, a one-time transfer of \$100,000 from Reclamation to the Service was made to fund conservation actions for the recovery of the threatened Chiricahua leopard frog *Lithobates chiricahuensis*.

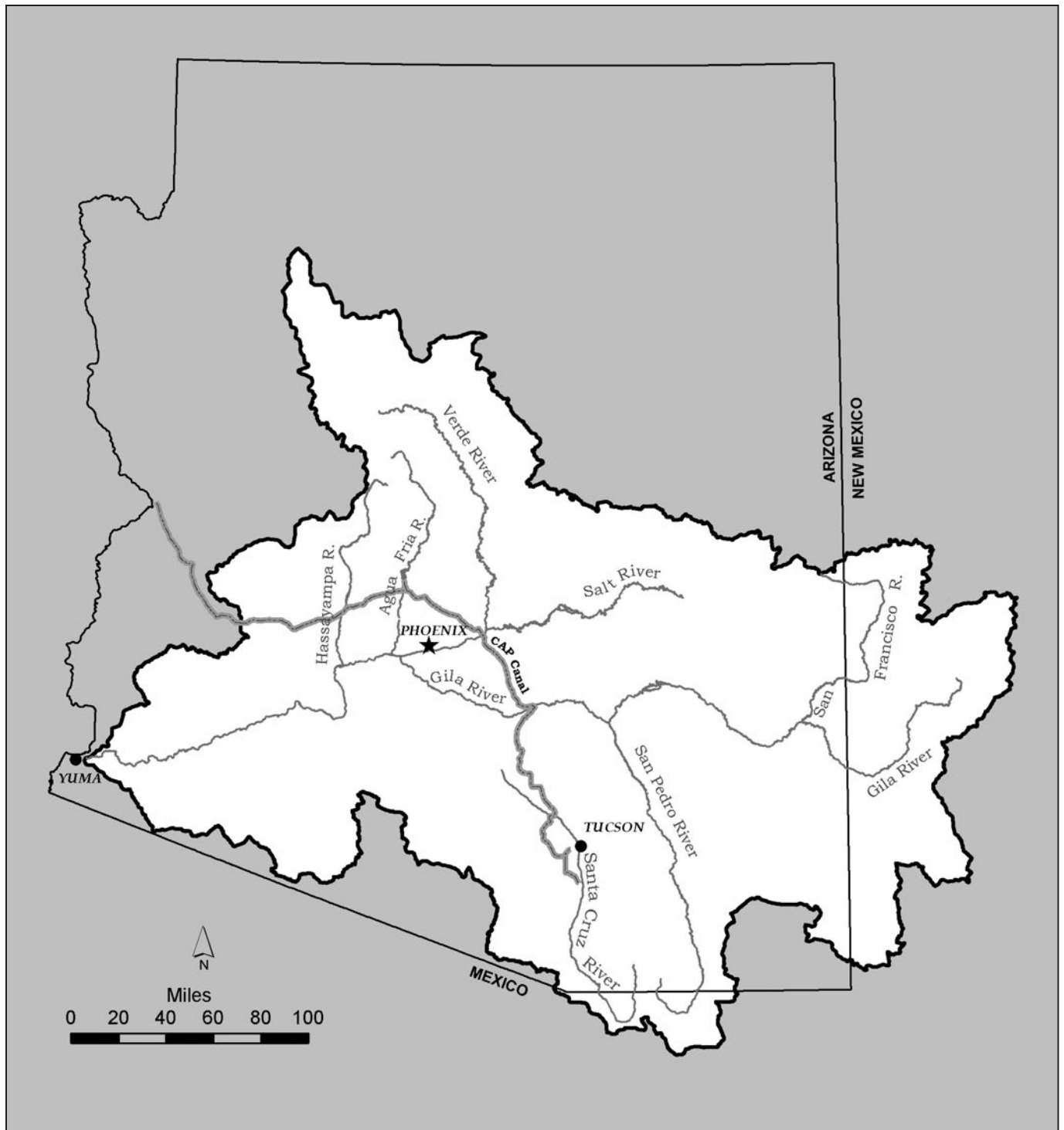


Figure 1—Map of the Gila River basin.

The principal goals of the GRBNFCP are to (1) enhance conservation status of federally listed and candidate fish species in the Gila River basin; (2) alleviate and diminish threats from nonnative aquatic species to native fishes; and (3) remove nonnative fishes that might enter the Gila River basin via the Central Arizona Project or associated pathways (USFWS and others 2007). While the focus of this Program is recovery of federally listed species, it is recognized that long-term

viability of protected species is accomplished only in the context of conservation of intact native fish assemblages and their associated environments.

Funding to conserve Gila River basin native warm-water fishes is limited. Monies from the Program are prioritized such that meaningful, achievable, and lasting conservation activities benefit native fishes according to recovery plan goals and other guidance documents (e.g.,

conservation agreements, habitat conservation plans, State Wildlife Action Plans, integrated watershed management plans, forest management plans, BLM habitat management plans). Highest priority projects for the Program are those that are necessary to (1) prevent extinction and stabilize populations in the wild, and (2) replicate rare populations in the wild. Actions needed to prevent extinction and stabilize populations in the wild include (1) construct fish passage barriers to protect existing populations, (2) control nonnative aquatic species above barriers, (3) establish new and maintain existing populations, and (4) implement other actions to remove immediate threats and thereby help prevent extinction. Actions needed to replicate rare populations in the wild include (1) safeguard streams for replication of rare populations; (2) where necessary, construct fish passage barriers and renovate streams; (3) undertake captive production, including development of propagation techniques; and (4) implement other actions to insure that rare populations are replicated and protected.

Additional priority is given to projects that (1) benefit the five priority species identified in the 1994 and 2008 biological opinions; (2) benefit multiple species, including all native fishes of the Gila River basin; (3) provide immediate on-the-ground benefit; or (4) address other activities pertaining to research or management that aid in conserving native fish populations and habitat.

Process

Reclamation transferred \$500,000 to the Service during the first 9 years of the Program, beginning in 1997. One half of that amount was for native fish recovery actions (RPA3), and one half for nonnative aquatic biota control actions (RPA4). The original biological opinion called for 25 years of transfers (USFWS 1994). Another biological opinion (USFWS 2008) contained conservation measures to fund the Program an additional 5 years, with annual transfers increasing to \$550,000. Thus, a total of \$16,050,000 over 30 years will be available under the GRBNFCP for the recovery of native Gila River basin fishes, and management against nonnative aquatic species.

The strategic plan (USFWS and others 2007) lists the process the GRBNFCP follows. The Policy Committee (Service, Reclamation, AZGFD, NMDGF) provides guidance to the Technical Committee, approves or rejects recommended projects, and deals with policy and political issues that may arise during implementation of the Program. Because the GRBNFCP is a federally funded program that implements a regulatory document, the Service and Reclamation make the final decisions on implementation if consensus cannot be reached with the State partners.

A Technical Committee comprised of one biologist from each of the above four agencies oversees project solicitation, evaluation, and recommendations for implementation. Ex-officio members are representatives from the U.S. Bureau of Land Management and the U.S. Forest Service. Ideas for original projects (called tasks) are based on recovery plans and are generated through discussions with ad hoc groups of biologists, agency, academic, and non-governmental organizations, private fish biologists working in the Gila River basin, and other entities as appropriate.

Once annual projects are selected, Reclamation transfers funds to the Service for disbursement to implementing entities. Some funds are retained by Reclamation for tasks they are better suited to conduct or contract (e.g., fish barrier designs), and the Service also has completed a few tasks. Tasks that are recovery or research projects require written reports; completed reports can be found on Reclamation's web page: <http://www.usbr.gov/lc/phoenix/biology/azfish/projlisting.html>.

Overview

About \$6.8M has been allocated through fiscal year 2011; half to each fund. The Service has disbursed or spent \$2.6M for RPA 3 and \$2.2 million for RPA 4, and Reclamation has disbursed or spent \$1M for RPA 3 and \$1.1M for RPA 4. A total of \$9.5M should be made available over the next 17 years.

Early in the Program's implementation, individual tasks were funded separately, and were often less than \$25,000. The state game and fish departments that implemented most of those tasks had a difficult time maintaining dedicated staff with such piecemeal budgets, and the contracting process to execute so many tasks was burdensome. Over the past 5 years, tasks performed by the two state wildlife agencies are lump-sum funded under multi-year umbrella agreements that facilitate retention of dedicated and qualified staffs and reduces contracting overhead costs. This change has also reduced the amount of unobligated funding and the lag time to disburse funds.

Arizona comprises about 93% of the 212,000 km² Gila River basin drainage area, with the remaining area in New Mexico and a small fraction in Sonora, Mexico. However, the upper Gila River in New Mexico remains an important, interconnected stronghold for species such as loach minnow and spikedace, and approximately 23% of funding has been directed to the state of New Mexico (table 1).

When funding is broken down by subbasin (table 2), the upper Gila has received 22% of the funding, as has the Verde River subbasin. The Verde has received similar funding due to the considerable conservation efforts at Fossil Creek, which so far have included renovating the stream and removing nonnative fishes, and stocking native fishes. Almost a third of the nonnative funds have been spent on tasks in the Verde subbasin. The San Pedro and middle Gila subbasins have also been well funded when compared to other subbasins, due to projects at the Muleshoe Cooperative Management Area and Bonita Creek, respectively.

Expenditures directed toward the five priority species have been generous for all but razorback sucker (table 3). Conservation opportunities for this species in the Gila River basin are limited, as the most appropriate physical habitat has intractable nonnative fish issues (Hyatt 2004; Marsh and Brooks 1989; Schooley and Marsh 2007). There have been many tasks that benefited spikedace and loach minnow because their conservation status is of the greatest concern among the five priority species. These two species were recently uplisted from threatened to endangered status (USFWS 2012). Also, a key goal of three of our large restoration projects at Fossil Creek, Bonita Creek, and the Muleshoe Cooperative Management Area has been the reestablishment of those two fish.

Table 3 also shows that unlisted species received copious funding. This is largely because of the several projects that also support populations of candidate-for-listing roundtail chub *Gila robusta* (USFWS 2009) and headwater chub *Gila nigra* (USFWS 2006). Both species are second priority species under the GRBNFCP strategic plan. The Fossil Creek project alone involves the two chubs, and four other unlisted species. In assigning funds to each species in a multi-species project, we estimated how much each species benefitted from the project. Because the two chubs were already present in Fossil Creek, and have done well post-renovation, much of the project costs were assigned to them.

Table 4 breaks down expenditures by project categories and shows that recovery funds (RPA 3) were spent on basic recovery actions: repatriation or reestablishment (36%), creation and management of refuges (13%), and surveys (11%). We also funded research (23%) on the genetics of the roundtail chub complex (*Gila* spp.) and desert pupfish *Cyprinodon macularius*, and on propagation of chubs, loach

Table 1—GRBNFCP expenditures (000s) through 2011, by fund, by state.

Fund	Arizona	New Mexico	Unkown/NA	Total
Recovery	\$2,668	\$916	\$28	\$3,613
Nonnative	\$2,482	\$626	\$115	\$3,223
Total	\$5,150	\$1,543	\$143	\$6,837

Table 2—GRBNFCP expenditures (000s) through 2011, by fund, by sub-basin.

Fund	Upper Gila	Santa Cruz	Verde	Salt	San Pedro	Middle Gila	Lower Gila	Unknown/Unclassified	Total
Recovery	\$912	\$200	\$487	\$639	\$481	\$330	\$25	\$591	\$3,665
Nonnative	\$623	\$195	\$1,026	\$229	\$448	\$467	\$28	\$203	\$3,219
Total	\$1,535	\$395	\$1,513	\$868	\$929	\$797	\$53	\$794	\$6,884

Table 3—GRBNFCP expenditures (000s) through 2011, by fund, by species.

Fund	Gila chub	Razorback sucker	Gila topminnow	Spikedace	Loach minnow	Other listed	Unlisted	Total
Recovery	\$439	\$70	\$448	\$910	\$614	\$241	\$992	\$3,714
Nonnative	\$305	\$161	\$406	\$739	\$737	\$145	\$693	\$3,186
Total	\$744	\$231	\$854	\$1,649	\$1,351	\$386	\$1,685	\$6,900

Table 4—GRBNFCP expenditures (000s) through 2011, by fund, by project type.

Fund	Research	Repatriation	Refuges	Surveys	Data	Misc	Renovation	Book	Barriers	Program	Total
Recovery	\$874	\$1,342	\$488	\$425	\$212	\$308	\$74	-	-	-	\$3,723
Nonnative	\$311	-	\$55	\$276	\$20	\$106	\$1,782	\$45	\$601	\$68	\$3,264
Total	\$1,185	\$1,342	\$543	\$701	\$232	\$414	\$1,856	\$45	\$601	\$68	\$6,987

minnow, and spikedace. About 10 percent of the nonnatives fund (RPA 4) went to research, largely focused on new and innovative control mechanisms of nonnative species. Our investment in research hopefully will facilitate species management and implementation of recovery actions by this and other programs. Almost three quarters of the nonnative management fund went to stream renovations and fish barrier projects.

Recovery of Natives (RPA 3)

Tasks under the recovery of natives fund are intended to lead to conservation and recovery of Gila River basin native fishes, mainly through on-the-ground projects. One of the tasks that underpins the entire recovery aspect of the GRBNFCP is development of a hatchery to (1) house wild stocks of imperiled populations as insurance against extirpation in the wild; and (2) propagate rare populations to assist with replicating them into new, protected streams. We developed and expanded the existing Bubbling Ponds Native Fish Research Facility in central Arizona to suit the unique needs of the stream-adapted native fishes of the Gila basin. We first developed methods to culture GRBNFCP-emphasis species that had not previously been propagated in a hatchery situation. Next, we acquired samples from most of the

most-threatened populations as insurance against loss in the wild, and began propagating and replicating them into protected wild streams. To date, replications of loach minnow, spikedace, Gila topminnow, and desert pupfish have been made to seven streams in the basin, and many more are planned.

Some of the major support projects for these recovery actions funded under RPA 3 included development of a larval fish key, characterization of the genetics of the roundtail chub complex (*Gila robusta*, *G. intermedia*, and *G. nigra*) and desert pupfish, determination of propagation techniques for loach minnow, spikedace, and the three Gila basin chubs, and development of refuge populations for Gila chub, topminnow, and pupfish.

Management Against Nonnatives (RPA4)

Tasks under the management against nonnatives fund are intended to ameliorate threats nonnative aquatic species are known to have on Gila River basin native fishes. Foremost among these was support for construction of six fish exclusion barriers to protect existing or replicated populations of many Program-priority species, evaluation of potential to develop new piscicide formulations, and purchases and

applications of existing piscicides and detoxification chemicals for restoration projects.

The Future

Because more than \$9M will be available for native fish conservation in the Gila River basin in Arizona and New Mexico under the GRBNFCP, we expect to continue strong recovery programs and threat mitigation for these fishes. Additional species listed under the ESA could be covered under the existing program, or may require additional measures if those species' conservation and recovery needs are not met by the existing GRBNFCP. We will continue placing barriers to protect native fish and their habitats, augmenting and reestablishing native species, and removing problematic nonnative aquatic species by the most efficacious means necessary.

As a result of ESA section 7 consultation on AZGFD's federally funded fish stocking program, a significant conservation program is being developed (USFWS 2011). The so-called CAMP (Conservation and Mitigation Program) has similar goals as the GRBNFCP, but covers the entire State of Arizona. Over a 10-year period CAMP is to conserve and recover its priority species and mitigate threats to those species. It is expected CAMP will be funded \$500,000 annually for 10 years from federal Sport Fish Restoration Funds. Because only loach minnow is a priority species in both programs, CAMP actions will cover a broader range of native aquatic species and a larger area. These complementary programs should prove greatly beneficial for native aquatic species in Arizona and parts of New Mexico.

As demonstrated above, multiple conservation and recovery projects benefitting native fish in the Gila basin have been completed. The GRBNFCP has been the most significant funding source for warm-water native fish recovery actions in the basin for more than a decade. The Program will continue to be a significant contributor to this important endeavor.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Mapping Ecological Systems in Southeastern Arizona

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***Abstract**—Beginning in 2007 in and around the Huachuca Mountains, the Coronado National Forest and other partners have been mapping ecosystems at multiple scales. The approach has focused on identifying land type associations (LTA), which represent the sum of bedrock and superficial geology, topography, elevation, potential and existing vegetation, soil properties, and local climatic variables. This mapping effort has been extended into the FireScape program, in which multiple partners utilize ecological land type mapping as a framework for fire planning across the Sky Island bioregion. Land type association maps for the Catalina-Rincon mountains (available at www.azfirescape.org) are used for managing ecological units (e.g., mixed conifer on granitic soils) typically no smaller than a thousand acres, and often much larger. Land type associations compliment raster-based sources of information such as LANDFIRE. Not surprisingly, the success of the project depends on an accurate depiction of vegetative and physical setting reality, not just interpretations of remote imagery. LTAs provide an intuitive and informative method of characterizing complex landscapes for planning and ecosystem management.*

Introduction

The notion of a landscape as a piece of land with a certain *character* has persisted for well over a thousand years (Calder 1981). That character might be of a lush river valley, a stony ridge, or a desert plain. These are natural units, with characteristic landforms supporting equally characteristic biota. For instance, in southeastern Arizona you might find creosotebush, little-leaf sumac, and viscid acacia dominating the alluvial fans at the toe of a limestone mountain. Landform, soils, geology, climate, hydrologic regime, and biota make what is recognized as an ecological system (Tansley 1935).

Mapping of ecological systems, or ecosystems, began with Humboldt and Bonpland's 1807 "Essay on the Geography of Plants," and has proceeded in earnest ever since. There remains much to do, in part because ecosystems exist at myriad scales, from course systems covering millions of square miles (e.g., humid temperate) to fine (e.g., mixed conifer on Mount Lemmon metasediments). To advance a single standard for ecosystem mapping at multiple scales, the United States Forest Service has adopted the National Hierarchical Framework of Ecological Units (table 1; Cleland and others 1997). At course scales, the hierarchy adopts Bailey's 1995 classification. In this paper we focus

on the finer scales, particularly the landscape scale and its associated ecological unit, the land type association.

Land type associations are typically no smaller than 1000 acres (404 ha), and are often much larger. They integrate landform and ecology into cohesive units that are intuitively apparent. For example, the typical structure of a rolling oak woodland on an alluvial fan—grass on the south aspects and trees on the north—is captured as a repeating pattern within a single land type association. However, when viewed with remotely sensed vegetation pixels, the pattern is fragmented by the assignment of at least eight different vegetation types (fig. 1).

Mapping land type associations is standard practice in much of the United States. In the northern Great Lake states they are used for landscape-scale assessments and planning, targeting opportunities for critical wildlife habitat restoration, and for on-the-ground silvicultural management (Almendinger and others 2000). The entire State of Missouri has been mapped with land type associations (Nigh and Schroeder 2002). In Arizona, however, landscape mapping is a recent development. Spurred by large wildfires in 2002-2003 that burned across jurisdictional bounds, Arizona land managers recognized the need for multi-agency landscape-level treatments to reduce fuel loads and reintroduce fire as a natural process in those ecosystems where it played a historic role. These efforts included landscape level mapping that began with the Huachuca Mountains and environs (Laing and others 2005), and continues today with the multi-agency FireScape project encompassing millions of acres of southeastern Arizona (www.azfirescape.org).

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Table 1—National hierarchy of ecological units (Cleland and others 1997).

Ecological unit	Planning and analysis scale	Principal map unit design criteria	Purpose, objectives, and general use
Domain	Global Continental Regional	Broad climatic zones or groups (e.g., dry, humid, tropical)	Broad applicability for modeling and sampling. Strategic planning and assessment. International planning.
Division		Regional climatic types (Koppen 1931, Trewatha 1968) Vegetational affinities (e.g., prairie or forest)	
Province		Patterns in dominant potential natural vegetation (PNV), macroclimate, geology	
Section	Subregion	Geomorphic province, geologic age, stratigraphy, lithology, regional climatic data, phases of soil orders, suborders, or great groups, PNV	Strategic, multiregional, statewide, and multiagency analysis and assessment.
Subsection		Geomorphic process, surficial geology, lithology, phases of soil orders, suborders, or great groups, subregional climatic data, PNV—formation or series	
Land type association	Landscape	Geomorphic process, geologic formation, surficial geology, elevation, phases of soil subgroups, families, or series, local climate, PNV	Forest or area wide planning, and watershed analysis.
Land type	Land Unit	Landform and topography (elevation, aspect, slope gradient, and position), phases of soil subgroups, families, or series, rock type, geomorphic process, PNV	Project and management area planning and analysis.
Land type phase		Phases of soil subfamilies or series, landform and slope position, PNV	

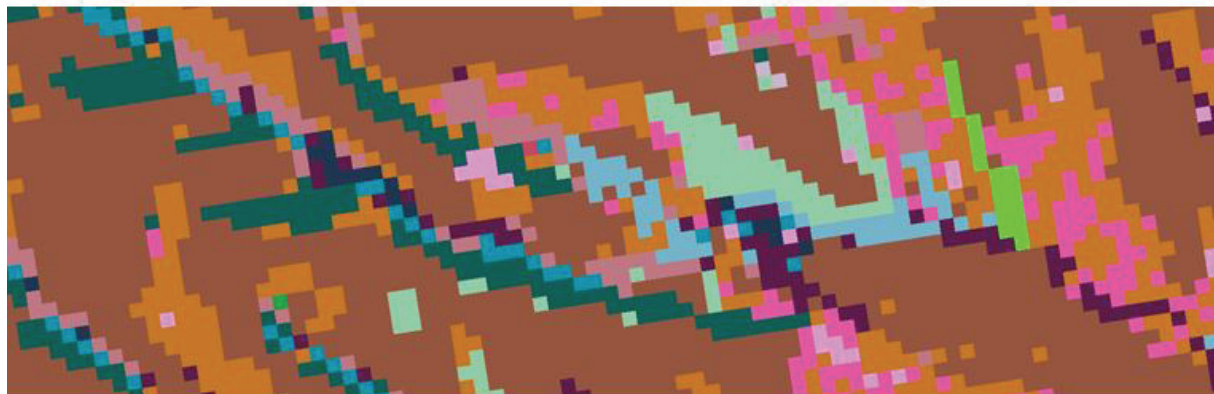


Figure 1—Oak woodland near Sonoita, Arizona, at about 5,000 feet elevation. This landscape is mapped as a single land type association, the Oak Tree Canyon dissected fans. In contrast, the same area is 8 different vegetation types represented as 30 meter square pixels in the lower image (raster data from LANDFIRE).

Methods

The National Hierarchical Framework of Ecological Units (Cleland and others 1997) assigns the relative importance of mapping criteria at different spatial scales (table 1). Note that the mapping criteria for the smallest units have little in common with the largest unit. For example, although local landform is important in recognizing land type associations, it plays little or no role in distinguishing larger ecosystems, where regional climate is paramount (fig. 2). In general, climate, as modified by topography, is the dominant criterion at upper levels, while geomorphic process, soils, and potential natural communities are more important at lower levels. The comprehensive “Terrestrial Ecological Unit Inventory Technical Guide” is an in-depth compendium of mapping techniques (Winthers and others 2005).

We mapped at three levels in southeastern Arizona: land type associations, land types, and ecological units. Land type associations are based primarily on bedrock and superficial geology, topography, elevation, potential and existing vegetation, soil properties, and local climatic variables (fig. 3). Land types are subdivisions of land type associations. Land types are based on more localized or finer scale topographic, geologic, soil, and plant species association properties than in land type associations (fig. 4). These units have land surface variations and other physical and biological properties that influence hydrologic function, moisture distribution and retention, which affect finer scale plant community composition and distribution. Land types range from having no or very few weakly developed drainage features, to being densely dissected by deeply incised washes and streams. Drainage characteristics (rocky, silty or sandy; confined or not; etc.) are strongly dictated by the land types within which they originate or through which they flow.

Finally, for management and analysis purposes, we aggregated similar land type associations into ecological landscape units, or simply ecological units. As used in this project, ecological units are groupings of land type associations with broadly defined similarities in vegetation, topography, geologic and soil features. They provide a “big picture” view of the ecosystems. Ecological units are intended to provide a framework for the assessment of existing conditions and departures, desired conditions, and environmental implications.

Scale	Example	Relative importance of:	
		Regional Climate	Landform
1000's of square miles	Section Sonoran Desert	▼	
10's to 100's of square miles	Sub-section Gila Bend Plain Desert Shrubland	▼	▲
1000's of acres	Landtype Association Catalina Foothill Fans		▲

Figure 2—An example of the relative importance of mapping unit criteria at different scales. For instance, at the level of Section, which typically encompasses thousands of square miles, regional climate is important, but landform is not. The importance of criteria are reversed at the level of land type association.



Figure 3—Three land type associations along Ash Creek, near the Rincon Mountains. The foreground is a broad floodplain with deep soils supporting mesquite, velvet ash, sycamore, and emory oak. The ridge on the right is largely composed of schist, and holds primarily ocotillo, mesquite, and beargrass. The ridge on the left is composed of granite and holds blue oak, hopbush, and manzanita.



Figure 4—Two land types from the same land type association: (a) the dominant vegetation is acacia and prickly pear; (b) palo verde and cholla.

Case Studies

Greater Huachuca Area

In southeastern Arizona, landscape scale mapping began with the Greater Huachuca Fire Management Group (the Coronado National Forest, the National Park Service, and Fort Huachuca (U.S. Army)) (Gebow and Lambert 2005). The group aimed to develop a management plan that would allow cross-jurisdictional treatments to return the region to something closer to its historical fire regime. The resulting map covered a half-million acres (Laing and others 2005).

The first step was to collect the relevant layers of data: soils, geology, topography, elevation, climate, existing vegetation, and remote sensing imagery. The analysis of the data began with determining which landforms are distinctive at the landscape level. For instance, assorted mountain landforms with bedrock at or near the surface are distinguished from the deep valley fill deposits. Alluvial fans and terraces adjacent to the mountains were separated from the valley floor. Initial mapping of landforms was aided by imagery from Landsat Thematic Mapper (TM) and USDA National Agriculture Imagery Program (NAIP) (imagery available at <http://aria.arizona.edu/>). We also used a shaded relief map that was digitally manipulated to the angle and position of the sun.

The landform patterns detected in the initial step usually coincide strongly with geologic materials and soil characteristics provided by National Resource Conservation Service (NRCS) soil surveys (available at <http://soils.usda.gov/>). Various biotic communities were determined through the use of the imagery, topography, existing vegetation maps (e.g., Southwest ReGAP, available at <http://earth.gis.usu.edu/swgap/>) and local experts. Associated fire regimes and condition classes were assessed by available literature (e.g., Kaib 1998). Precipitation and temperature data were compiled from the USFS General Ecosystem Survey. The last step was to validate the units on the ground and to make appropriate corrections. The final units, developed with feedback from the fire-planning group, represented 15 land areas that were relatively consistent in terms of geologic material, landform, and vegetation patterns.

Land Type Associations of Southeastern Arizona

The Huachuca Area map prompted the National Park Service, the U.S. Forest Service and U.S. Geological Survey to conduct additional mapping of 109 land type associations over nearly two million acres in southeastern Arizona (Cleland and others 2008). The study area, which included the Greater Huachuca Area, is bounded to the south by the international border, to the west by the Santa Cruz River, to the east by the San Pedro River, and by Redington Pass to the north, between the Catalina and Rincon Mountains (fig. 5). The methodology was similar to that used to map the Greater Huachuca area, using GIS layers pertaining to geology, soils, elevation, slope, and existing vegetation. However, because of increased variation in local climate over the larger study area, we calculated potential evapotranspiration (PET) using the Thornthwaite (1948) equation (White and Host 2002). Using PRISM data (Daly and Taylor 2000) we also calculated mean monthly temperatures for the time period of 1961 through 1990. These data were included in the description of each land type association, along with physiography, soils, geology, vegetation, and fire history over the last 35 years, during which 1,307 fires burned a total of 243,039 acres. Land types were also delineated and briefly described within the context of their respective land type associations.

Catalina–Rincon FireScape

The Coronado National Forest, University of Arizona, and other partners sponsor the ongoing FireScape project (www.azfirescape.org). FireScape works to advance the science of fire management from a landscape and ecological perspective in southeastern Arizona. The most comprehensively mapped lands to date are 700,000 acres of the Catalina and Rincon Mountains outside Tucson, a study area that included the Little Rincos and the east slope down to the San Pedro River. Methods were similar to prior phases (above), with two exceptions: the addition of draft geology maps provided by the Arizona Geological Survey (Reynolds, 2007), and significantly more time in the field. We photographed all but one land type association, and took notes on the associated vegetation. The data on these 300 photo points and 200 species were uploaded onto the website, where they appear on dynamic maps of the mapping products (www.azfirescape.org).

We mapped 120 land type associations in the Catalina and Rincon Mountains. We also subdivided land type associations into 327 land types, as well as aggregating land type associations into ecological units for planning and public education (fig. 6). At lower elevations (i.e., pediments, fans and valleys), the land types were based primarily on soil surveys and drainage features; at higher elevations (usually roadless and steep and lacking detailed soil surveys), the land types are recognized by surficial and bedrock geology, vegetation, and gross physiographic differences. For example, the east face of the Rincos between 4000 and 6000 ft (1524 to 1851 m) is home to Madrean oaks and pinyon pine, two species of similar size but different response to fires (oaks resprout, pines don't). Hiking the mountain revealed a clear distinction in substrate preference between the two species, with pinyon dominating habitat with exposed bedrock, and the oaks preferring colluvium (landslides). The distinction was readily apparent to the eye, but less so from the current generation of remotely sensed pixel vegetation maps, such as LANDFIRE and ReGap landcover (cited above), which rendered the landscape as 30 meter pixels.

Conclusions

Have the ecosystems maps been useful? Yes. The map of the Greater Huachuca area, for instance, provided the 15 mapping units used as “project areas” in a successful three-agency, whole-landscape Environmental Assessment (EA) for fire treatments (EA available at <http://www.azfirescape.org/content/huachuca-firescape-project-documents/>). The Huachuca units similarly served as the basis for a Biological Opinion that addressed effects of fire treatments on 10 Federally listed species. Likewise, the ecological units map of the Catalina and Rincos is being used to guide the identification of treatments, and the analysis of the effects of those treatments to meet environmental compliance requirements. For example, the LANDFIRE fuels layer can be combined with the ecological units layer to examine fire behavior at the landscape scale.

However, comparing LANDFIRE pixels (raster data) and ecological unit polygons (vector data) can be a problem; the mapping units often don't match up. The ecological unit called “desert-oak transition on granitics,” for example, has no straightforward equivalent in the LANDFIRE vegetation lexicon. Consequently, as the FireScape project has moved on to the Chirichaus, Dagoon, and Dos Cabezas mountains in the southeastern Arizona, we have adopted names already in use by LANDFIRE (FireScape maps available at <http://www.azfirescape.org/chiricahua-dagoons-dos-cabezas/>).

With this adjustment, ecological system maps and remotely sensed pixels can not only be used in tandem, but also to check on their

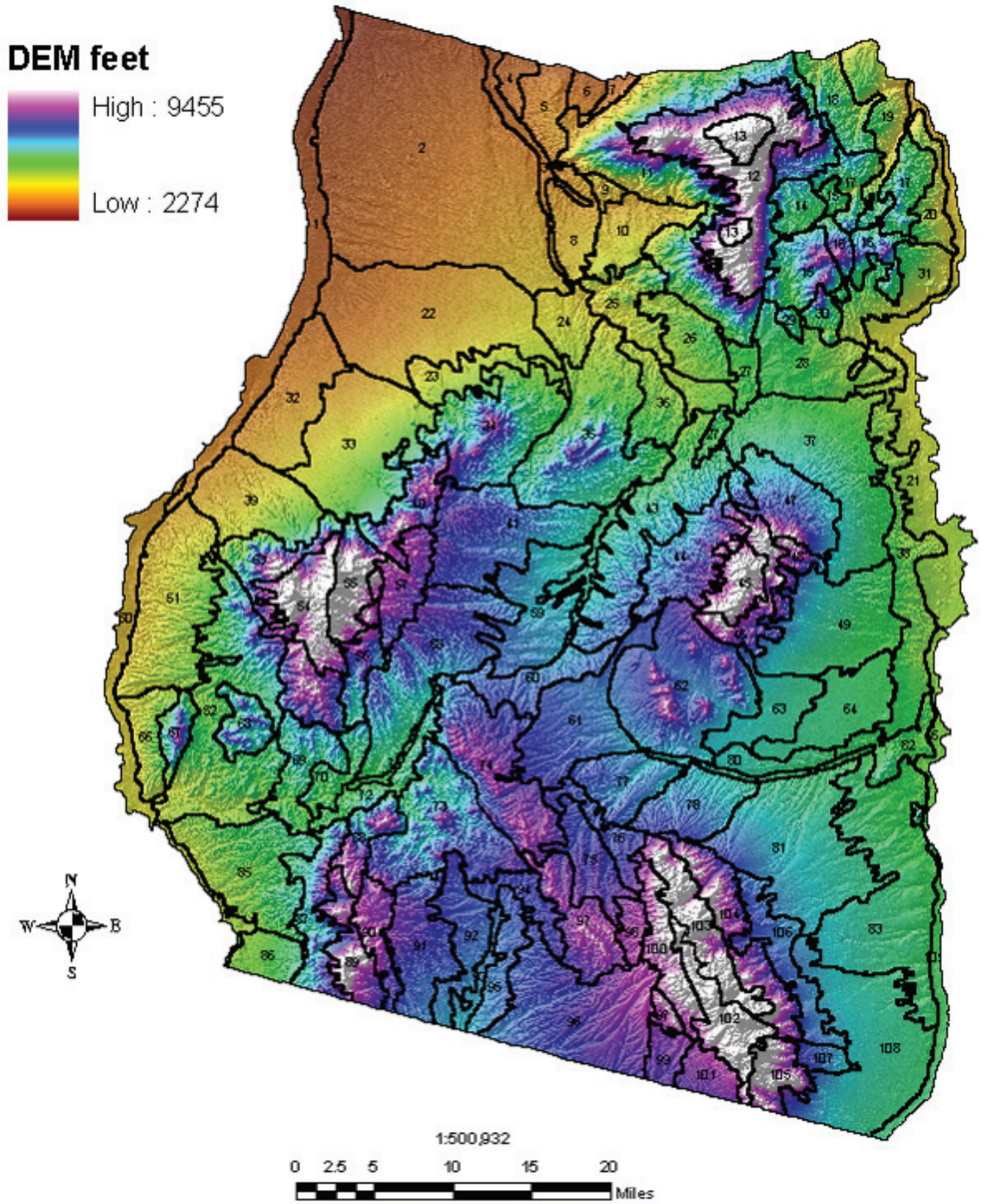


Figure 5—Land type associations of southeastern Arizona, with digital elevation model. The international border is the southern boundary (from Cleland and others 2008).

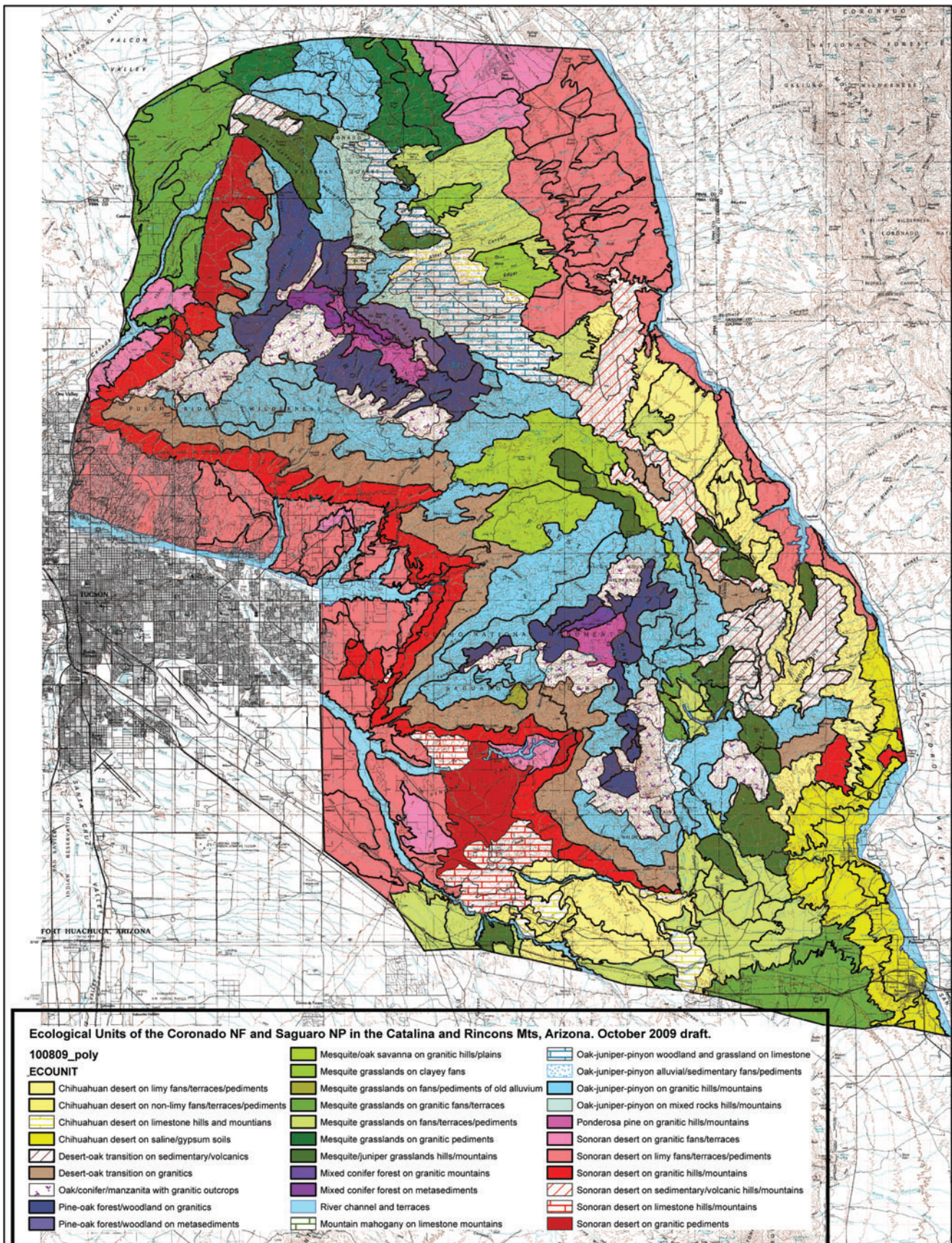


Figure 6—Ecological units of approximately 700,000 acres of the Catalina and Rincon Mountains, Arizona. Polygon boundaries within ecounits show the smaller land types and land type associations.

accuracy. When two maps disagree, it is time to get into the field and take a closer look.

Acknowledgments

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein. NOTE: This paper was originally part of this session and belatedly moved to this location, so page numbers are not sequential within these proceedings.

Potential for Extending Major Land Resource Areas into Northern Mexico

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Abstract—There is a significant history of cooperative efforts between Mexico and the United States on natural resource management issues. Mexico and the United States have jointly conducted research and developed range management technologies. Bringing these technologies together and improving technical communications are an ongoing process. This paper discusses a potential tool that can provide a common denominator for both countries to more easily frame, describe, and share data relative to rangeland resources. The objective is to present possibilities for utilizing current data and provide a vehicle that can facilitate technical communications. Existing maps including climate and elevation were used to define probable areas of Chihuahua and Sonora that would be similar enough to Major Land Resource Areas (MLRAs) of Arizona to consider them an extension of those MLRAs. Reconnaissance surveys were made to compare soils and vegetation to those described in Arizona. Comparisons were also made between Ecological Sites (ESDs) used in the United States with those developed in Mexico by COTECOCA. A preliminary map was developed that represents probable boundaries of MLRA 41 if extended from the U.S. border into the states of Chihuahua and Sonora. Some sites were mapped to test application of U.S. ecological site descriptions with on-ground conditions in Chihuahua. The potential for extending MLRA boundaries from the United States into Mexico are feasible and realistic. This would facilitate the direct use of Ecological Site Descriptions across borders and improve exchange of rangeland data between the two countries.

Background and Objectives

Our presentation today is not the first discussion of this subject. There have been two previous accounts of the effort to explore the possibilities of extending Major Land Resource Area (MLRA) boundaries from the southern United States border into Mexico. These are Rebecca MacEwen and others paper (2005) *Defining Boundaries Across Borders: A Case Study Extending a Major Land Resource Area Into Mexico*, and Philip Heilman and others (2000) *A Framework for Cooperation Across the U.S./Mexico Border*.

The project demonstrates the cooperative nature of several agencies and individuals. All activities were under the leadership of the Southwest Watershed Research Center of the USDA-ARS. The principal partner in Mexico was the Instituto Nacional de Investigaciones de Forestales, Agrícolas, y Pecuarias (INIFAP). Alicia Melgoza played a critical role in assisting with scheduling activities in Mexico, advising on conditions and characteristics of vegetation, and helping with plant identification. Antonio Chavez, former Director of Campo Experimental La Campana, made the facilities of La Campana available to

serve as a headquarters site for those involved in the project. Rafael Fierros of Comisión Técnico Consultiva para la Determinación Regional del los Coeficientes de Agostadero (COTECOCA), Chihuahua devoted his time and assistance to the effort, regarding COTECOCA site identification and plant identification.

The USDA Natural Resources Conservation Service (NRCS) provided excellent technical expertise with the participation of Dan Robinett, Range Conservationist, Tucson, Steve Barker, State Range Conservationist Phoenix, and Don Breckenfeld, Soil Scientist, Tucson. In addition, the producers of Ejido Nuevo Delicias, Chihuahua, cooperated by making their lands available for site correlation work. This paper will present an overview of the activities and findings in an attempt to identify limits of an MLRA boundary when extended from the U.S. border in Arizona to the states of Chihuahua and Sonora. Emphasis will be on an appreciation and understanding of the materials and data bases available that indicate the compatibility of the concept with other data bases and agencies rather than just the effort made to test extending MLRAs into Mexico.

Classification System

MLRAs are part of a hierarchical classification system that is important in classifying soils and ecological sites. The system was developed by the Soil Conservation Service, now NRCS, and published as USDA Handbook 296 in 1965. The handbook was revised in 1978, and published in 1981. This version was again revised and updated and published in 2006. The classification system has important and

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valuable application, particularly related to rangelands in terms of ecological site work, and soil/site correlation. The system components are shown below:

NRCS Hierarchical Classification System:

LAND RESOURCE REGIONS

MAJOR LAND RESOURCE AREAS

LAND RESOURCE UNITS (or Common Resource Areas)

ECOLOGICAL SITES

SOIL SERIES

Since the 1960's, NRCS has been using the soil and ecological site databases as the basic units of a hierarchical natural resource classification system called Major Land Resource Areas (MLRA's). This system provides a basis for making decisions about national and regional agricultural concerns, helps identify needs for research and resource inventories, provides a broad base for extrapolating the results of research within national boundaries, and serves as a framework for organizing and operating resource conservation programs" (Fox and others 1999).

Land Resource Regions

The broadest category in the hierarchy is **Land Resource Regions**. The region of most interest for this paper is Region D, Western Range and Irrigated Region shown in figure 1. It makes up 549,725 square miles (1,424,480 square kilometers). This is the largest of all the land

resource regions in land area. It is a semi-desert or desert region of plateaus, plains, basins, and many isolated mountain ranges.

Major Land Resource Areas (MLRAs)

Regions are further subdivided into Major Land Resource Areas (fig. 2). This level of classification is the subject of this document.

MLRA lines end at the international border. The characteristics that the lines represent do not end at the border, but extend to some unknown extent into Mexico. This recognition was the fundamental rationale for exploring where the boundaries might lie within Mexico. Some important aspects of the MLRA system are:

- It is nationwide in scope.
- It is updated and refined periodically. Some states have refinements that reflect county level determinations.
- It is not an isolated concept useful only to NRCS. MLRAs have been correlated with other agency classification systems.

In addition to use by the Bureau of Land Management in its use of ecological sites, it has also been correlated with other agency classification systems. The information shown below illustrates the correlation that has been done to date. USDA Handbook 296 (2006) cross-references MLRAs with Environmental Protection Agency's (EPA) Level III Ecoregions, and with United States Forest Service (USFS) ecological units for the conterminous United States. A few cross references are shown in table 1. The fact that MLRAs have been



Figure 1—Region D: Western Range and Irrigated Region (source: USDA NRCS Agriculture Handbook 296).

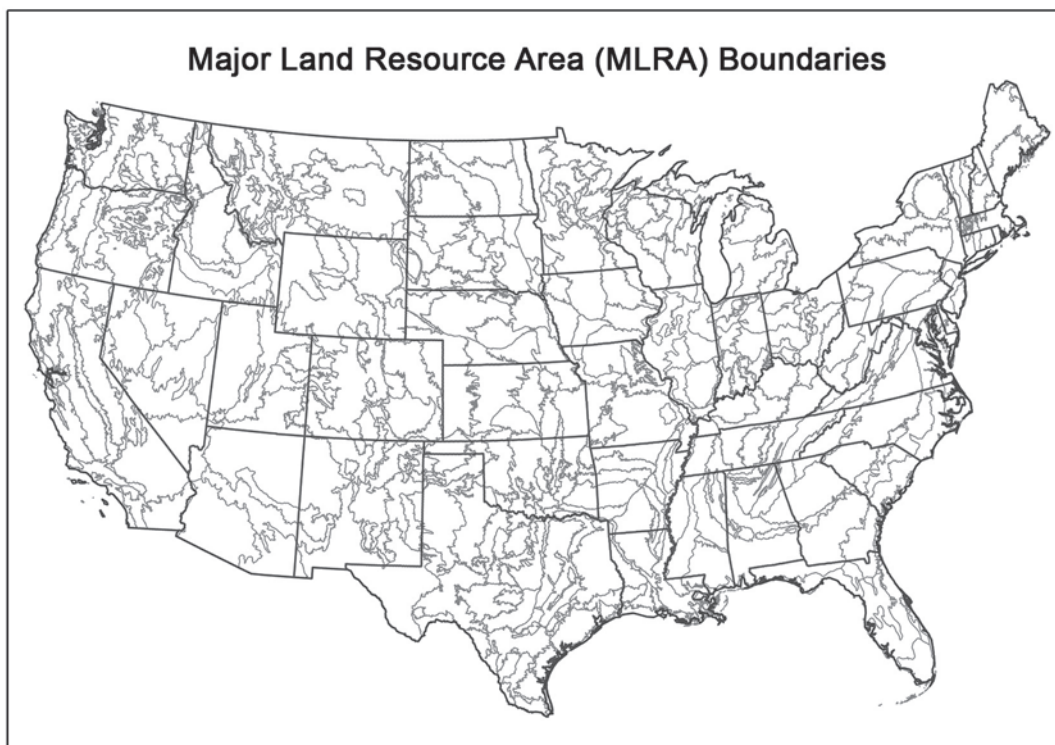


Figure 2—Major Land Resource Areas of the United States (source: U.S. Department of Agriculture Handbook 296), .

Table 1—Cross reference of MLRAs, USFS, and EPA.

MLRA	USFS	EPA
39 Arizona and New Mexico Mountains	M313A White Mountains-San Francisco	23 Arizona/New Mexico Peaks-Mogollon Rim
40 Sonoran Basin and Range	322B Sonoran Desert	81 Sonoran Basin and Range
41 Southeastern Arizona Basin and Range	321A Basin and Range	79 Madrean Archipelago
41 Southeastern Arizona Basin and Range	321A Basin and Range	24 Chihuahuan Deserts
42 Southern Desertic Basins, Plains, and Mountains	321A Basin and Range	24 Chihuahuan Deserts

correlated to other agency classification systems broadens their utility and expands their range of application. Similar applications and interest are shown in The Nature Conservancy’s work in the Apache Highlands Ecoregion, Gori and Enquist (January 2003).

In our primary area of interest, the following figure illustrates the MLRAs as they occur in Arizona. One can see that in the Southeastern corner of Arizona lays MLRA-41, Southeastern Arizona Basin and Range, which is the primary focus of this paper. MLRA 41 is further subdivided into three Common Resource Areas (Climatic Zones), or Land Resource Units (fig. 3):

- Common Resource Area 41-1 Mexican Oak-Pine Woodland and Oak Savannah
- Common Resource Area 41-2 Chihuahuan-Sonoran Desert Shrub Mix
- Common Resource Area 41-3 Southern Arizona Semidesert Grassland

The extension of MLRAs into Mexico would allow the direct use of Ecological Site Descriptions (ESDs) for “on-the-ground” ecological

interpretations. In addition to being a valuable grazing management tool, ecological site descriptions provide a documented biodiversity benchmark in the list of plant species that are known to occupy a particular ecological site. In addition to providing a list of documented plants, the ESD also indicates the potential primary production range of each species, or groups of species. This provides a new level of information subject to interpretation for biodiversity studies.

Activities and Methods

Initial work consisted of reconnaissance surveys, focusing on observations of vegetation and soil characteristics as compared with that of ecological sites described in Arizona. A primary tool used in the evaluation of MLRA boundaries was the application of Geographical Information System (GIS) technology. Virtually all the activities of the project were correlated with and incorporated into a GIS database that proved invaluable in evaluating and displaying findings.

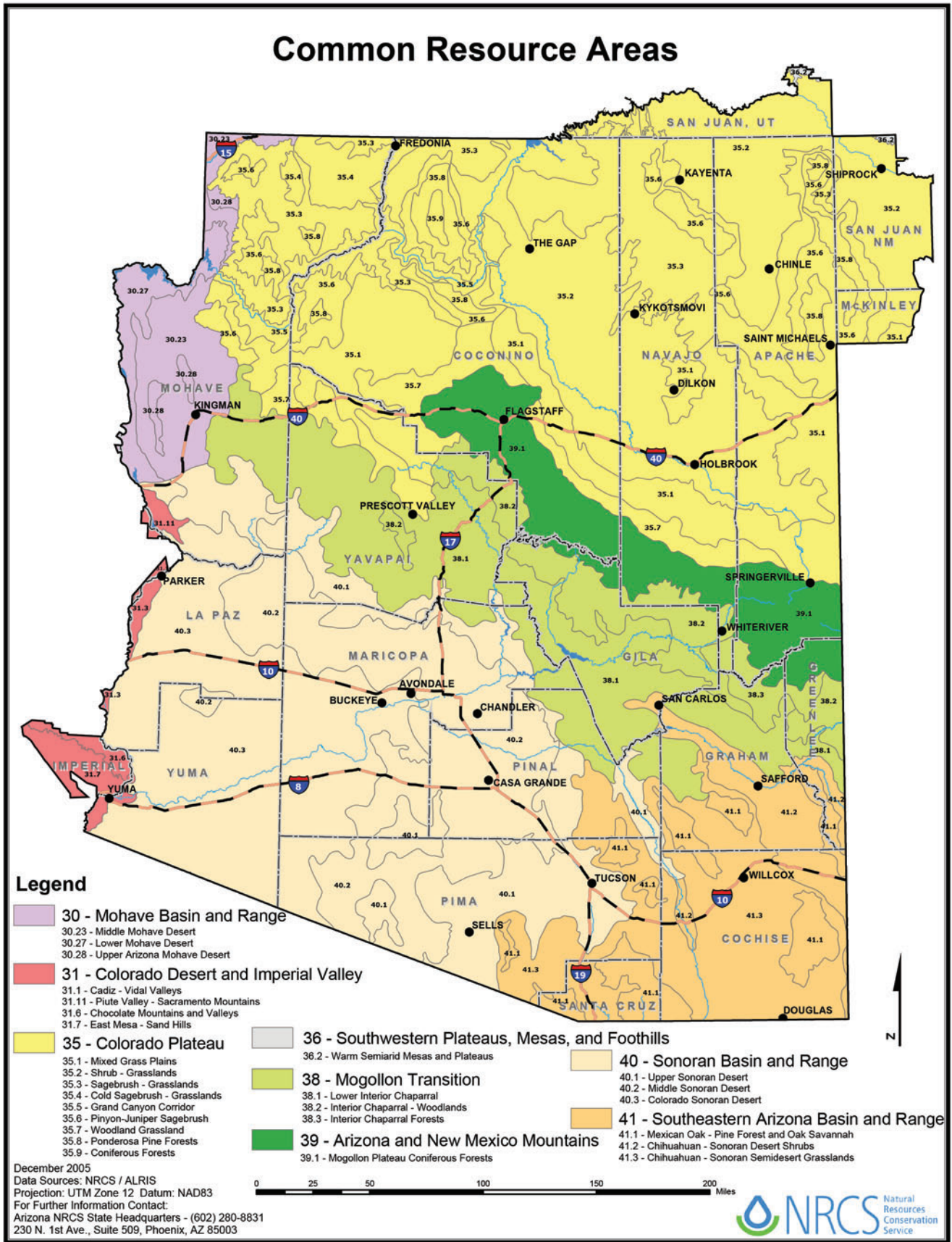


Figure 3—MLRAs and CRAs of Arizona.

Based on information developed from the initial reconnaissance trips and other sources, a map was developed by Heilman (2000) and MacEwen (2005) showing a suggested extension of MLRA boundaries (fig. 4). This preliminary map was largely developed by digitizing vegetation maps of Sonora and Chihuahua from Brown and Lowe’s (1994) *Biotic Communities of the Southwest*. Ultimately, the Brown and Lowe based map turned out to be an excellent first approximation that provided valuable guidance for field determinations.

Further field work included investigations by Don Breckenfeld, NRCS Soil Scientist. Soil profiles were described and compared to known soil series in Arizona. All of the soil profiles described were determined to be very similar to soil series associated with MLRA-41 (fig. 5).

Existing maps relative to climate and elevation were used to define probable areas of Chihuahua and Sonora that would be similar enough to Major Land Resource Areas (MLRAs) of Arizona to consider them an extension of those MLRAs. Comparisons were also made between Ecological Site Descriptions used in the United States with site descriptions developed in Mexico by COTECOCA.

Hydrologic studies were also included in the field activities. A rainfall simulator was used to evaluate hydrologic conditions as related to ecological conditions and soils on several sites within the projected MLRA area. The technology and procedures are described by Stone and Paige (2003) (fig. 6).

As another evaluation of site similarities, a small ranch just south of La Campana was mapped using NRCS ESDs. Most of the sites were very similar to ecological sites in Arizona, and should be considered to be adequate for management interpretations (fig. 7). The Arizona site descriptions used in developing the above map, and a corresponding translation name used are as indicated in the table 2:

Comments Regarding Range Sites, Forage Production Sites, and Ecological Sites

Both the United States and Mexico have invested major resources in their respective efforts to define and classify rangeland units for the purposes of conducting inventories, analysis of rangeland resources, and as range management tools. The most significant units developed



Figure 5—Describing soil, Chihuahua.



Figure 6—Rainfall simulator studies, Chihuahua.

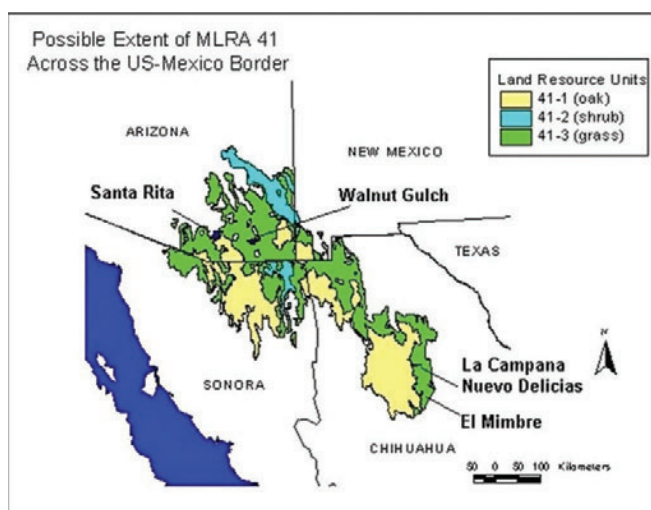


Figure 4—Possible extent of MLRA 41 boundaries (from Heilman and others 2000).

for these purposes have been the Ecological Site concept in the United States, and the Sitios de Productividad Forrajera (Forage Production Sites) in Mexico. The Range Site (now Ecological Site) concept was adopted by the USDA Soil Conservation Service (now Natural Resources Conservation Service [NRCS]) in 1949, based on the work of E.J. Dyksterhuis (1949).

The principal application of Range Sites was in conducting inventories and rangeland analyses during the process of range management planning with ranchers on privately owned lands. The purpose was to help individual ranchers manage rangeland resources to improve rangeland conditions and increase economic returns for the rancher.

The primary purpose of the COTECOCA sites (fig. 8), at the time they were developed and mapped, was to establish grazing capacities for the different major plant community types for the entire nation. Heilman and others (2000) made several important observations regarding the resolution differences between ecological sites and forage production sites:



Figure 7—Ecological sites mapped in Chihuahua.

Table 2—Site names and map symbols

Arizona Site Name	Translation	Map Symbol
Shallow Hills 41-1	Lomas – Suelos Poco Profundo	LPP
Loamy Hills 41-1	Lomas Francosa	LF
Loamy Upland 41-3	Llano Francoso	LIF
Granitic Hills 41-3	Lomas Graníticas	LG
Sandy Loam Upland 41-3	Franco Arenosa	FA
Shallow Upland 41-3	Llano – Suelos Delgados	LID



Figure 8—A portion of Chihuahua showing COTECOCA site mapping

Defining sites on an ecological, rather than forage, basis leads to a finer resolution of sites in the U.S. In Arizona, 503 ecological sites are defined over a total area of 29m hectares. In Chihuahua, 64 forage production sites are defined for 24m hectares. Per unit area then, there are almost 7 times as many ecological sites defined in Arizona as there are forage production sites defined in Chihuahua. Both approaches distinguish areas with the potential for homogeneous stands, such as sacaton bottoms, as separate sites. However, the Natural Resources Conservation Service defines more sites in areas with heterogeneous plant communities, even though those sites could all have the same forage production capability.

Results

A refined map of probable MLRA boundaries was developed that represents estimated boundaries of MLRA—41 if extended south from the U.S. border into the states of Chihuahua and Sonora. Figure 9 shows the adjustments made to the original map that reflect, hopefully, a more accurate definition of MLRA boundary lines.

Conclusions

In keeping with the subject of this conference “Biodiversity and Management,” we hope that the materials that have been presented in this paper will provide some insight in recognizing the opportunities

that exist for further, and broader in scope, collaboration between the United States and Mexico.

Although the effort described in this paper demonstrates the potential for extending MLRAs into Mexico it should not be considered definitive. Boundary lines that were developed need further refinement and additional field evaluations. However the lines can be considered to be a reasonably accurate first approximation, and can be utilized with a fair degree of confidence. The potential for extending MLRA boundaries from the United States into Mexico is feasible and realistic. This would facilitate the direct use of ESDs across borders and improve exchange of rangeland data between the two countries. Mexico would have a direct benefit from the use of MLRAs as a valuable and useable management tool through the direct use of ecological site descriptions in range management planning. COTECOCA site descriptions should not be overlooked. They represent descriptions of all grazing sites within the country, and have been mapped on a state basis. It is probable that Brown and Lowe maps can be effectively applied in future efforts to extend MLRA boundaries in other parts of Mexico.

This is an opportune time to work with Mexico in the refinement of site descriptions. The NRCS is in a continuing process of revising Ecological Site Descriptions and comparisons could be made between COTECOCA descriptions resulting in correlating the two systems. This would be valuable in strengthening the ecological interpretations of COTECOCA sites, and would allow for Mexican researchers, rangeland managers, planners, and others to tap into an existing, rich

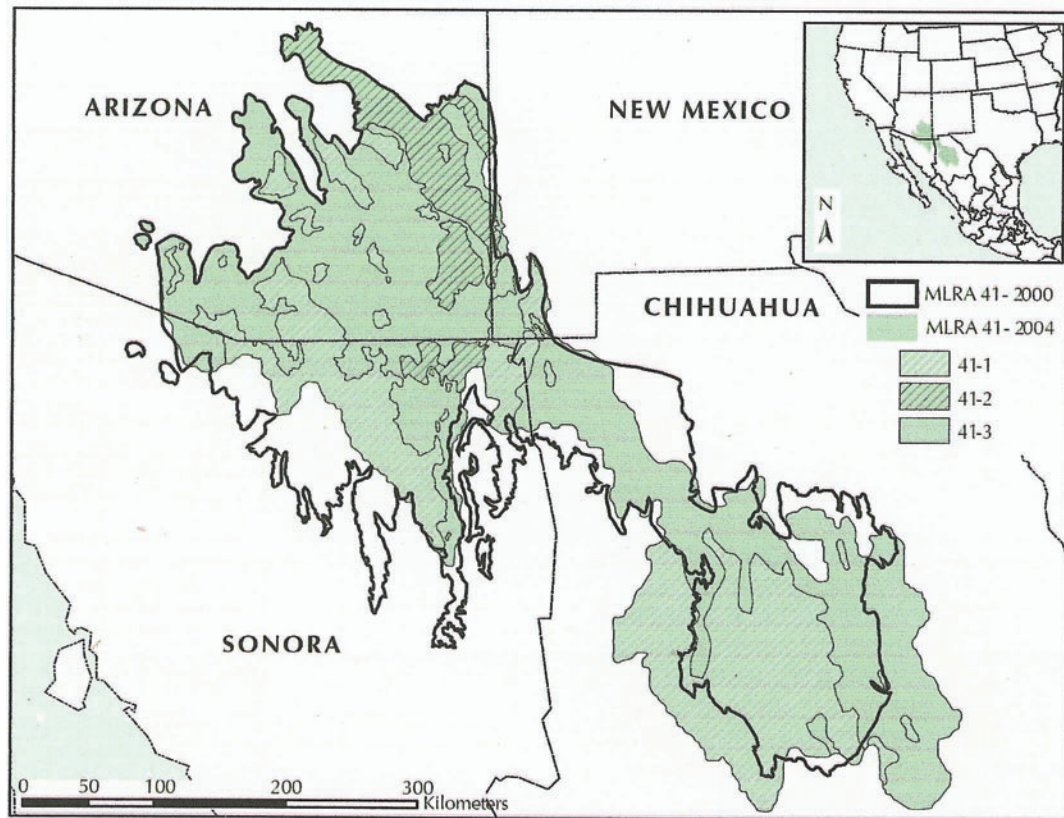


Figure 9—Adjustments made in projected MLRA boundaries in Sonora and Chihuahua.

database that will increase the value and utility of a neglected, but valuable resource. Utilizing MLRAs in Mexico would be a valuable addition to international communications, research, and exchange of data. MLRAs can serve as a common denominator for classifying and framing technical data that currently is not being utilized. The wheel does not have to be reinvented.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Into the Third Dimension: Benefits of Incorporating LiDAR Data in Wildlife Habitat Models

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Abstract—LiDAR (Light detection and ranging) is a tool with potential for characterizing wildlife habitat by providing detailed, three-dimensional landscape information not available from other remote sensing applications. The ability to accurately map structural components such as canopy height, canopy cover, woody debris, tree density, and ground surface has potential to improve wildlife habitat models because animals interact and respond to three-dimensional habitat features. Prior to LiDAR, accurate measurements of structural features were difficult to obtain over large areas as other remote sensing data are based on two-dimensional spectral responses. The Southwest harbors a large diversity of unique vegetation communities, each with an associated wildlife assemblage with various management needs. Managers can use LiDAR to accurately characterize vegetation and landscape structural characteristics for entire districts or management units. Data surfaces derived from the LiDAR point cloud can be readily incorporated into species-specific or multispecies habitat models. Although LiDAR has received much attention in characterizing forest structure, fewer studies ($n = 29$) have suggested or incorporated this technology to improve wildlife habitat models specifically. Herein we provide a review of current LiDAR applications in wildlife habitat models, provide future directions, and detail how LiDAR can increase our ability to represent the world that animals experience.

Introduction

Managing landscapes for diversity and persistence of wildlife is dependent on our understanding of vegetative, structural, physiographic, and bioclimatic needs of species and how these factors contribute to vital parameters such as growth, survival, and coexistence (Morrison and others 2006). Increasingly, managers are faced with the need to monitor, conserve, and predict a diversity of plant and animal species and their specific habitat requirements over broad spatial scales; scales at which ground-based sampling is cost prohibitive, or infeasible due to remoteness. The vegetative communities and associated faunas in the Madrean Archipelago are extremely diverse, and harbor many endemic and endangered species (Lasky and others 2011; Poulos and others 2007), requiring substantial monitoring efforts over large areal extents. To conserve and manage the unique biotic assemblages on state and federal lands within the Madrean Archipelago, improvement in inventory of species diversity, identification of habitat requirements for a variety of taxa—from arthropods to large mammals—identification of areas of particular conservation importance, and continued monitoring of these areas to ensure species viability and probability of persistence would be beneficial.

An important management tool is the ability to correlate the presence of a species with particular physiographic and vegetative features thought to be important components of the species' habitat. Many of these species-specific physiographic and vegetative features can be characterized with remote sensing data and, therefore, mapped over large areas to produce a habitat model (Lurz and others 2008). Habitat variables in such models are typically represented with remote sensing data obtained from passive sensors intercepting wavelengths of reflected light or heat from the earth's surface. These remote sensing products are only capable of representing the complexity of the landscape in two dimensions and do not directly measure structure (Vierling and others 2008; Lefsky and others 2002), which limits our ability to accurately describe and predict wildlife-habitat relationships. Active sensor technologies, such as light detection and ranging (LiDAR), can improve wildlife habitat models by more accurately describing fine-scale, spatially explicit, three-dimensional structural features related to animal use, occurrence, and reproductive success (Vierling and others 2008) and measure these features across entire management units, mountain ranges, or districts (Reutebuch and others 2005).

LiDAR data is generally collected from a laser-emitter scanner linked to an accurate global positioning system and inertial measurement unit (Reutebuch and others 2005); the resolution and quality of the data depends on both the scanner and the pulse density (Evans and others 2009; Reutebuch and others 2005). LiDAR data can be broadly categorized into two classes depending on the type of sensor: large-footprint wave-form data in which the pulse-return intensity over time is digitized, and small-footprint discrete return data (fig. 1) in which the spatial coordinates at which each laser pulse intersects an object are recorded (see Anderson and others 2005; Evans and others 2009;

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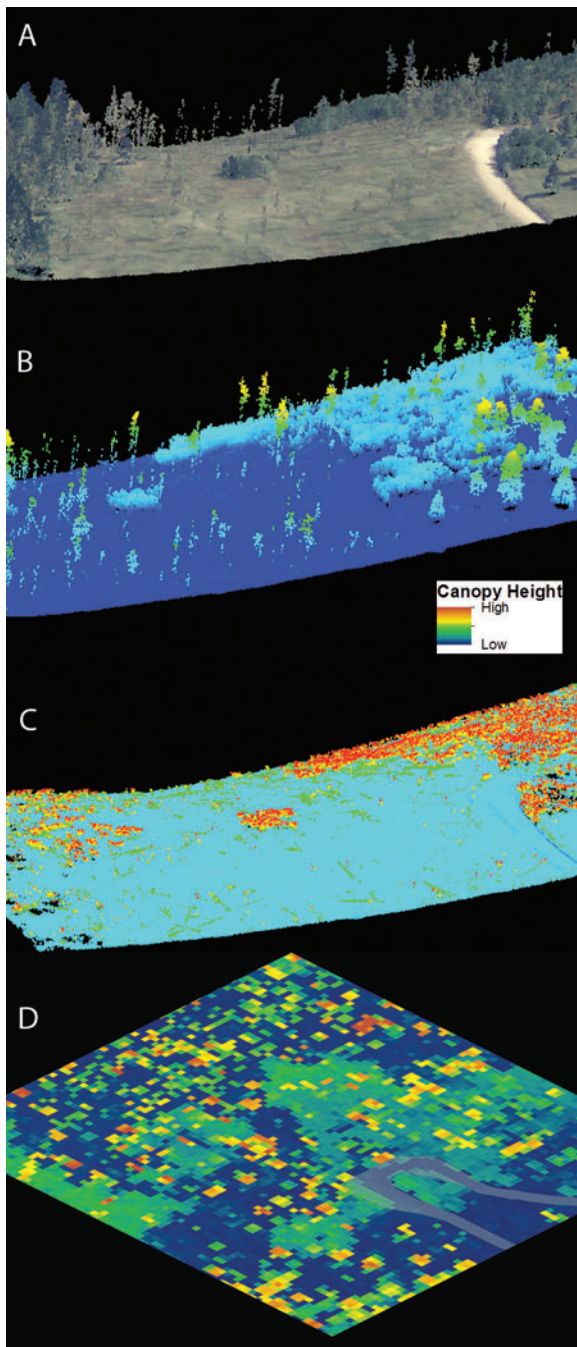


Figure 1—A visualization of discrete, multiple return LiDAR data: (A) LiDAR point cloud draped with georeferenced aerial imagery, (B) Height of LiDAR pulse returns above the ground showing all vegetation structure and density, (C) Height of LiDAR pulse returns ≤ 2 meters above the ground showing shrub/sapling vegetation structure and density, (D) raster layer created from mean canopy height surface, 3 m pixel resolution.

Lefsky and others 2002; Reutebuch and others 2005; and Vierling and others 2008 for excellent reviews). There are positives and negatives to each method (Evans and others 2009) and both provide unique structural information not available from spectral or thermal sensor technology and can greatly improve our ability to classify landscape

features and describe how animals relate to them. Herein we provide a review of current LiDAR applications in wildlife habitat models.

Methods

Literature Review and Synthesis

We conducted a search of published literature referenced in the Science Citation Index via Thompson Reuters Web of Science, accessing all years through 30 March 2012. We used five search routines: (1) wildlife habitat AND LiDAR in “Title,” (2) habitat AND LiDAR in “Title,” (3) wildlife habitat in “Topic,” LiDAR in “Title,” (4) habitat in “Topic,” LiDAR in “Title,” and (5) habitat AND LiDAR in “Topic.” We tabulated the number of references returned in each search iteration. We selected references relevant to studies of wildlife-habitat relationships for further review. For each selected reference, we summarized main objectives, methodology, main conclusions, and management implications either stated or implied. We also examined whether the study was taxa specific, whether LiDAR-derived variables were correlated with landscape features of interest and whether or not incorporation of LiDAR-derived variables enhanced or significantly improved predictions and classification. We compiled these data to identify current uses of LiDAR in habitat models, commonly utilized LiDAR-derived variables, and new ideas or emerging techniques.

Results

Many studies refer to LiDAR as a tool potentially applicable to wildlife habitat assessment, monitoring, classification, and prediction, as indicated by the substantial number of references returned via our most general search criteria (fig. 2; habitat AND LiDAR in “Topic,” $n = 154$), indicating the growing interest in and awareness of LiDAR technology. Relatively few references explicitly mention use of LiDAR in wildlife habitat applications (fig. 2; $n = 18$). However, a considerable subset of total references specifically address the applicability of LiDAR data to predict species presence, diversity, reproductive performance, or for creating variables that represent important structural features useful in wildlife habitat models. We reviewed 59 studies relating the use of LiDAR data to wildlife habitat characteristics and summarized some common research aims (table 1). The stated aims included assessment of LiDAR’s ability to identify or quantify organisms, predict species presence, diversity, or performance, and predict physical and vegetative characteristics associated with species presence.

Of the 59 publications that we reviewed, the majority (45 or 76%) assessed the predictive capability of LiDAR-derived variables relative to field-based measurements; of these, all but two reported significant relationships between LiDAR-derived and field-based measurements (table 1). Just over half (31 or 53%) of the publications focused on a particular species or group of organisms (e.g. breeding forest birds, tree species, forest spiders, fish communities). Of these, all but two publications focused on using LiDAR to describe important habitat characteristics, animal relationships to structural features, and predicting occurrence based on these structural affinities. Avian habitat relationships were the most common area of taxon-specific focus (table 1; 13 or 42%). We detected no use of the term “LiDAR” within publications from wildlife-specific journals such as *The Journal of Wildlife Management* or *Wildlife Research*.

Many LiDAR-derived variables are strongly correlated with standard, field-based habitat measures, allowing for accurate predictions at multiple spatial scales (table 2; Hyde and others 2005; Lefsky

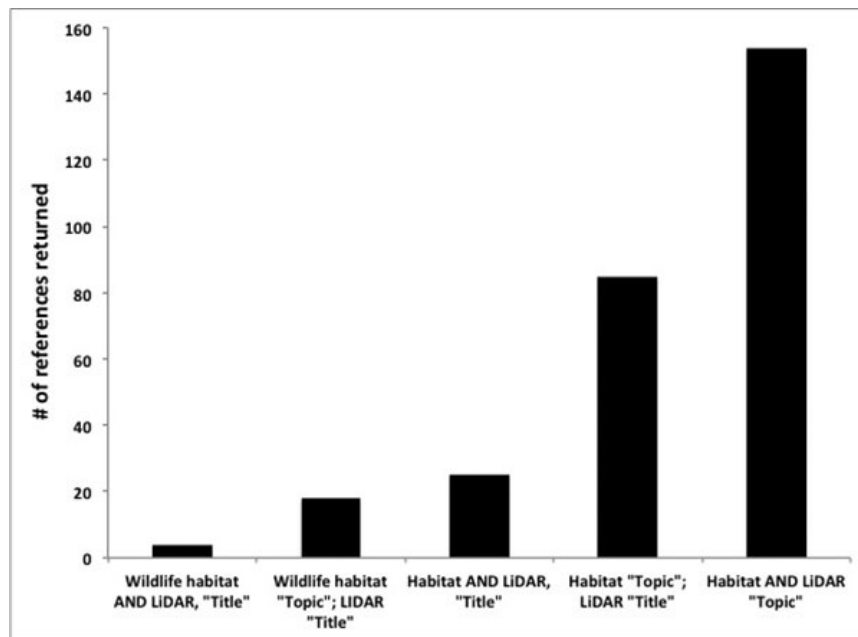


Figure 2—Number of published journal articles referencing LiDAR, habitat, and wildlife habitat returned from Web of Science search criteria including all years through 30 March 2012.

Table 1—Summary of common research aims from 59 studies relating the use of LiDAR data to wildlife habitat characteristics

Stated aims	# results	% of stated aims	Additional characteristics	# studies
– Assess potential to identify or quantify organisms based on structural association	3	3.3	Predictive?	45
– Assess potential to predict species performance based on structural associations	3	3.3	Significant relationship between LiDAR data and variable of interest?	43
– Assess potential to predict physical characteristics	8	8.7	Incorporate spectral data?	12
– Review or comment	9	9.8	Improvement over spectral data alone?	9
– Discuss applications	11	12.0	Multiscale?	10
– Assess potential to predict vegetation characteristic	17	18.5	Taxa specific?	31
– Classification and mapping	17	18.5	Taxa considered:	
– Assess potential to predict species presence or diversity based on structural associations	24	26.1	amphibians	1
			reptiles	1
			mammals	2
			arthropod	4
			fish	4
			plants	6
			birds	13
Total aims	92			

and others 2002; Vierling and others 2008). Some variables, such as canopy cover, tree or vegetation height, and canopy volume within various height categories, were obtained directly from the point cloud or waveform intensity, whereas other LiDAR-derived variables are secondarily estimated based on the relationship between primary LiDAR metrics and plot-based measurements such as basal area, biomass, and leaf area index (table 2; Dubayah and others 2000; Lefsky and others 2002; Ruetebuch and others 2005; Vierling and others 2008). Still other LiDAR-derived variables provide novel information that is difficult to obtain from field-based measurements such as highly accurate terrain models and secondarily derived metrics of slope, aspect, and rugosity (a measure of surface height variability).

Information unique to LiDAR data includes measures of pulse-return intensity, which can be used to distinguish among live and dead trees (Bater and others 2009; Kim and others 2009) and identify ephemeral wetlands beneath forest canopy cover (Julian and others 2009), as well as vertical structural complexity and volume. Vertical structural complexity and volume can then be used to model fine-scale differences in canopy use within bird communities (Clawges and others 2008), or specific nesting requirements of a single species (Goetz and others 2010). Additionally, new variables may be developed for describing vegetative composition, complexity, and physiographic-vegetative associations based on ratios, linear relationships, or other novel combinations, which may further refine our ability to describe

Table 2—Examples of LiDAR-derived metrics and applications for incorporating LiDAR variables in wildlife habitat models. Primary LiDAR metrics can be obtained directly from the LiDAR point cloud. Secondary LiDAR derivatives must be modeled based on the relationship between primary metrics and ground-based training data. References include studies incorporating metrics and/or applications.

LiDAR-derived metric	Primary or secondary?	Applications	LiDAR method	References
Canopy surface model	Primary	Height of trees or other features without terrain subtracted. Depict elevation of canopy surface above sea level.	Discrete return, waveform	Andersen and others 2005; Graf and others 2009
Canopy cover/closure	Primary	Produced from canopy surface model, important in habitat models for many bird and forest obligate species, but also those that prefer open areas	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002; Hyde and others 2005; Martinuzi and others 2009
Canopy/vegetation height model	Primary	Height of trees or other features with terrain subtracted. Identify forest seral stages, habitat preferences for species with varying affinities for canopy, portions of the canopy, or stand age	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002; Hyde and others 2005; Graf and others 2009
Canopy/vegetation profiles	Primary	"	Waveform	Dubayah and Drake 2000; Lefsky and others 2002; Goetz and others 2010
Canopy base height	Primary	Identify inhabitable canopy area when subtracted from canopy height	Discrete return, waveform	Andersen and others 2005
Canopy volume	Primary	Identify differences in canopy structure among forest age classes, distinguish among canopy structural affinities of various species	Waveform	Lefsky and others 2002
Coefficient of variation vegetation height	Primary	Identify forest seral stages and be used with field data to predict occurrence of snags and woody debris	Discrete return	Bater and others 2009
Digital terrain model (DTM)	Primary	Delineate streambeds, create very accurate DEM, slope, aspect, ruggedness layers	Discrete return, waveform	Reutebuch and others 2003; Graf and others 2009
Digital Elevation Model	Primary	Elevation and other interpolated surfaces: slope, aspect, rugosity commonly used in habitat models	Discrete return, waveform	Goetz and others 2010; Martinuzi and others 2009
Foliage height diversity	Primary	Parse LiDAR vegetation returns within height intervals to estimate shrub or foliage density, important for ground nesting birds or other species that respond to foliage density at varying heights	Discrete return, waveform	Clawges and others 2008; Martinuzi and others 2009
Return intensity	Primary	Distinguish between live and dead biomass as dead trees, vegetation, and water have low return intensity compared to live trees and vegetation	Discrete return	Kim and others 2010
Standard deviation of vegetation height/ mean absolute deviation height	Primary	Index of stand structural complexity, age, seral stage, used to identify snags	Discrete return, waveform	Graf and others 2009; Martinuzi and others 2009
Vertical distribution of canopy structure	Primary	Estimate above-ground biomass, identify forest seral stage	Waveform	Dubayah and Drake 2000; Goetz and others 2010

Table 2—Continued

Above-ground biomass	Secondary	Provides an estimate of forage availability and, when combined with multispectral band information, forage quality	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002; Hyde and others 2005
Basal area	Secondary	Provides information on forest structure and density, an important variable in habitat models of forest-dwelling species	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002
Canopy complexity/diversity	Secondary	Describes the vertical complexity of vegetation structure, important for arboreal species	Waveform	Lefsky and others 2002; Goetz and others 2010
Diameter Breast Height (DBH)	Secondary	Provides information on stand age, tree maturity could serve as a proxy for food or nest site availability	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002
Leaf area index (LAI)	Secondary	Provides an estimate of forage availability and, when combined with multispectral band information, forage quality	Discrete return, waveform	Dubayah and Drake 2000; Lefsky and others 2002
Timber/vegetation volume	Secondary	Identify habitable areas within tree or shrub cover	Discrete return, waveform	Dubayah and Drake 2000; Clawges and others 2008
Vertical distribution ratio	Secondary	Differentiate among areas with high and low understory canopy structure, important for species sensitive to understory vegetative cover	Waveform	Goetz and others 2010

important habitat features and predict presence of organisms on the landscape (Vierling and others 2008). Below, we briefly examine four application domains common to wildlife studies that have benefitted from incorporation of LiDAR-derived variables; we also provide a summary of LiDAR-derived variables applicable to studies of wildlife-habitat relationships (table 2).

Habitat Mapping

LiDAR’s ability to accurately characterize physical terrain and vegetative structure can contribute to landscape classification efforts (Lefsky and others 2002). Classification techniques often include classification and regression trees, machine learning algorithms such as Random Forest (Martinuzzi and others 2009), and image segmentation via object based image analysis routines (Arroyo and others 2010). Adding three-dimensional structure increases a classification routine’s ability to resolve among similar vegetative types and fine-scale physiographic features. When structural information such as canopy height, return intensity, and rugosity are combined with multispectral data from satellites like Landsat ETM, QuickBird, IKONOS (Arroyo and others 2010; Bradbury and others 2005; Clawges and others 2008) or hyperspectral data, classification accuracy is improved. With sufficient training data, LiDAR can be used to accurately classify, map, and model important structural habitat variables over broad spatial scales (Bradbury and others 2005; Lefsky and others 2002). Resulting classifications or maps can then be incorporated into predictive models of species presence or use of an area (Graf and others 2009; Martinuzzi and others 2009).

Predicting Presence or Use

The ability to predict an organism’s presence and monitor for its continued persistence is a central goal among land managers and wildlife biologists alike (Hyde and others 2005). Because LiDAR data directly measures structural features that animals respond to (i.e. select for) at hierarchical spatial scales, LiDAR-based parameters have potential to improve the predictive capability of species distribution and probability of use models (Bradbury and others 2005; Seavy and others 2009). LiDAR-derived variables can be used to correlate fine-scale structural associations measured in the field and map these over large spatial extents, indicating areas where a species or community is likely to be found. For example, many species require dead trees (snags) for nesting (bluebirds, woodpeckers, and many tree squirrels), and may only use an area if such features are available. LiDAR can be useful in identifying or predicting the presence of snags, either based on the tendency for older forest structural stages to harbor more woody debris (Bater and others 2009; Martinuzzi and others 2009), or by the change in the intensity of LiDAR pulse returns based on the amount of dead wood in a plot (Kim and others 2009). Once maps of snag-class presence or absence were created for a single mountain, Martinuzzi and others (2009) used this information to predict the mountain-wide probability of use for several bird species based on their affinities for snags of particular sizes.

Availability of preferred microclimates can allow species to persist in otherwise extreme environments (Suggitt and others 2011). LiDAR’s ability to accurately map fine-scale topographic features has potential for creating variables based on species’ microclimate needs, and thermally important areas such as suitable sites for rearing neonates and likely locations for ectotherm burrows could be mapped at broad scales.

Correlates of Habitat Quality

Defining and improving habitat quality are topics of considerable interest in the wildlife literature and major goals for efforts such as land management, conservation, restoration, and endangered species recovery. In reality, however, habitat quality is difficult to assess, especially with metrics meaningful to the organism of interest (Hinsely and others 2006). Because of the difficulty in measuring structurally complex landscapes, habitat quality is often inferred from measures of reproductive success within a defined area. If reproductive success is strongly correlated with specific physiographic or vegetation structural features, then LiDAR can be used to define areas of predicted high reproductive success and habitat quality. LiDAR-derived metrics of canopy height were strongly correlated with mean chick body mass in *Parus major* over a 7-year study, and the direction of this relationship changed depending on springtime temperatures (Hinsley and others 2006). With this complicated interaction between climate, position in canopy, and nestling success established, it is conceivable that mean nestling mass and inferred habitat quality could be predicted annually over an entire forest based on LiDAR data and climate predictions.

Correlates of Biodiversity

With the threat of climate change and associated disturbance events, there is an increased need for rapid biological assessments of state and federal lands to both inventory and monitor species diversity and focus conservation efforts on areas associated with high biodiversity (Bergen and others 2009; Lesak and others 2011). Structural complexity and heterogeneity in both vegetation and physiography are associated with higher levels of plant and animal diversity relative to less complex sites (Bergen and others 2009). Therefore, LiDAR-derived variables should aid in identifying areas of high biodiversity and in predicting biodiversity of certain species assemblages based on their structural affinities (Bergen and others 2009). Forest dwelling beetle diversity and richness were correlated with LiDAR-derived measurements of elevation and tree height (Müller and Brandl 2009). Songbird species richness in deciduous forests was related to LiDAR-derived measures of forest structure such as canopy and midstory height and midstory density, with intra-guild species diversity (e.g. ground vs. aerial foragers, edge vs. interior specialists) described by different forest structural metrics (Lesak and others 2011).

Discussion

Proven Tool

LiDAR technology has become increasingly accessible and affordable over the last 10-15 years and continues to improve, providing valuable datasets that can be used by resource managers toward a variety of applications, from forestry and watershed science, to wildlife conservation and management over large spatial extents (Lefsky and others 2002; Ruetebuch and others 2005; Vierling and others 2008). While not all LiDAR data is equal (Evans and others 2009), it is evident that LiDAR technology and its various applications are no longer just theoretical. LiDAR technology has proven a useful tool when applied to many wildlife-habitat studies, and will continue to be refined. Every article we reviewed touted LiDAR's ability to quantify (often accurately) landscape and aquatic structural features that organisms identify as habitat, to map fine scale habitat associations over large areas, and to improve predictive models of species presence, use, reproductive success, and overall biodiversity.

Combining LiDAR and multispectral datasets allows for maximal exploration of species' biotic and structural associations to more adequately represent the real world that animals inhabit and to which they respond.

Promising Future

In the Madrean Archipelago, LiDAR data collection has begun for the Coronado National Forest, and LiDAR-derived metrics promise to improve forest inventory and monitoring efforts, including habitat assessment and modeling for a variety of wildlife species. The sheer size and topographic and biotic diversity of national forests like the Coronado are representative of the challenges this vast and complex region poses in terms of conservation and management, and also represent an opportunity to demonstrate the benefits of incorporating LiDAR data to accurately describe, quantify, monitor, and conserve its great biological diversity and natural resources.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Grasslands

Sustaining the Grassland Sea: Regional Perspectives on Identifying, Protecting and Restoring the Sky Island Region's Most Intact Grassland Valley Landscapes

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Abstract—Grasslands of the Sky Islands region once covered over 13 million acres in southeastern Arizona and adjacent portions of New Mexico, Sonora, and Chihuahua. Attempts to evaluate current ecological conditions suggest that approximately two thirds of these remain as intact or restorable grassland habitat. These grasslands provide watershed services such as flood control and aquifer recharge across the region, and continue to support dozens of species of concern. Prioritizing conservation interventions for these remaining grassland blocks has been challenging. Reliable data on condition and conservation value of grasslands in the region have not been systematically summarized. State and national boundaries further complicate efforts to identify where the best remaining habitats and populations of grassland obligate species still exist. We present results of an effort to merge grassland condition assessments, compile information on target species locations, and identify “priority grassland valley landscapes” across the region. We evaluate these priority landscapes in terms of the number of target species, critical threats, and enabling conditions for long-term conservation success such as activity by local cooperative groups dedicated to sustaining their landscapes. Lastly, we discuss the opportunities and challenges of designing and implementing effective restoration activities in these large multi-jurisdictional landscapes.

Introduction

The grasslands of central and southern Arizona, southern New Mexico, and northern Mexico, referred to here as Sky Island grasslands, form the “grassland seas” that surround small forested mountain ranges, transitioning into desert scrublands as elevations drop, or into foothill woodlands or chaparral as elevations rise. At the continental scale, Sky Island grasslands form a unique setting where the large blocks of Great Plains and Chihuahuan Desert grasslands east of the Rockies and Sierra Madre Mountains spill over a low spot in the Continental Divide. This ecotone geography and the ecological gradients associated with “Sky Island mountains and grassland seas” add tremendous floral and faunal diversity to the region as a whole (McClaran and Van Devender 1997). Grassland valley landscapes here are often recognized as distinct and important places by their respective human communities, who self-organize to varying degrees in order to benefit from and protect the ecological and economic values of these places.

Sky Island grasslands have undergone dramatic vegetation changes over the last 130 years including encroachment by shrubs and trees, loss of perennial grass cover and spread of non-native species (Humphrey 1987; Bahre 1991). The causes for these vegetation changes have been the subject of debate and range from changes in regional climate to human impacts including poorly managed livestock grazing and suppression of wildfires (Humphrey 1958; Buffington and Herbel 1965; Hastings and Turner 1965; Cable 1967; Wright 1980; Bahre 1985, 1995; Swetnam 1990; Brown and others 1997; McPherson and Weltzin 2000).

Changes in grassland composition and structure have not occurred uniformly across the borderland region, nor are they solely the consequence of past climatic events or human impacts but are ongoing today (Archer 1989; Bahre 1991; Brown and others 1997; Ceballos and others 2010). These changes, combined with increased fragmentation due to exurban development and agricultural conversion, have caused significant declines in grassland species, especially wide-ranging ones.

Although the above studies, as well as others, have documented change to grasslands locally, there have been only a few attempts to characterize the extent of change or assess current grassland condition of borderland grasslands at broader scales (Cox and Ruyle 1986; Enquist and Gori 2008; Yanoff and others 2008).

In 2009, The National Fish and Wildlife Foundation (NFWF) launched its Sky Island Grassland Initiative, a 10-year plan to protect and restore grasslands and embedded wetland and riparian habitats in the Sky Island region (fig. 1). The Initiative emphasizes grassland restoration, protecting threatened land and water, and restoring

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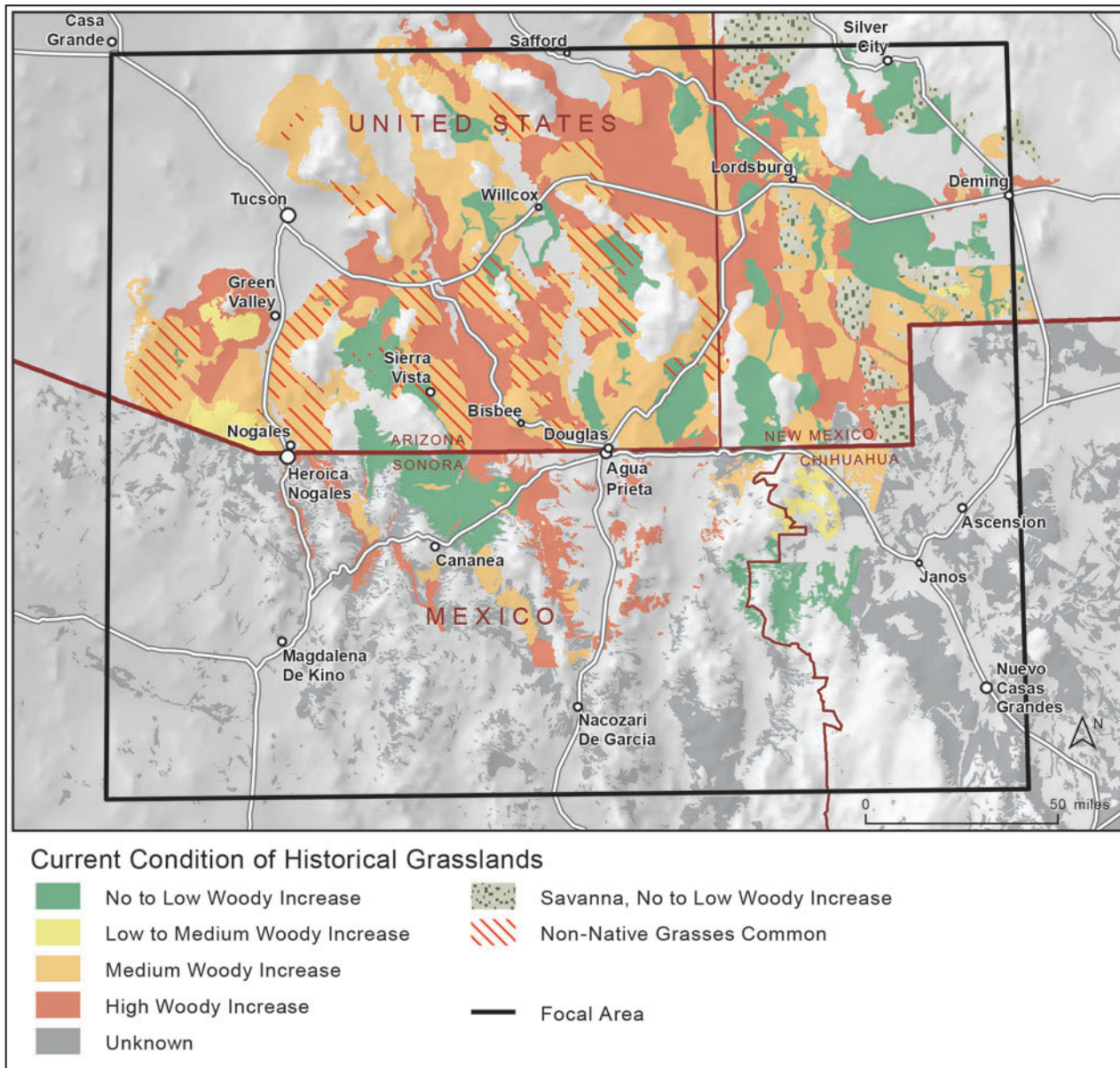


Figure 1—Current condition of Grasslands in the Sky Island focal area.

populations of target wildlife species (NFWF 2009). The Foundation anticipates investing millions of dollars to achieve these goals and expects to leverage additional millions in federal, state and private funds. The question is: where will this investment yield the greatest returns in terms of restoring grassland health and recovering wildlife species across the region?

This report attempts to answer this question at a regional scale by integrating two recent spatial assessments of the historical extent and current condition of Sky Island grasslands and savannas as well as compiling information on the occurrence of grassland-dependent wildlife and species of concern. Using this information and an expert-based approach, we identify 12 priority landscapes where the potential for restoring grasslands and recovering target species have the greatest probability of success. We identify and evaluate these priority landscapes based on their size, condition, landscape context, number of target species and natural communities, and human

enabling conditions for long-term conservation success. The latter factor includes the existence of partnerships, such as local cooperative groups dedicated to sustaining their landscape; land protection efforts; and ongoing ecological restoration and management.

Methods

Mapping Grassland Condition

Two recent assessments of historical grassland extent and current condition form the basis of this Sky Island Grassland Assessment and cover most of the historical and remaining grasslands and savannas in the Sky Island region: the Apache Highland Grassland Assessment (AHGA; Gori and Enquist 2003) and the New Mexico Rangeland Ecological Assessment (REA; Yanoff and others 2008). The AHGA defined a series of grassland condition classes using expert opinion

and the peer-reviewed literature to define threshold values for shrub cover. Mapping of these condition classes was done by 24 range management specialists from federal and state agencies, academic institutions and non-governmental organizations for the U.S. and a combination of experts and LANDSAT satellite imagery analysis for Mexico. Mapping was at approximately 1:100,000 to 1:250,000 scale. AHGA condition classes were defined by percent woody plant cover, compared to historical condition, and whether the grass species were native, non-native, upland or riparian (table 1). The AHGA considered fire to be a major natural disturbance that controlled woody plants and maintained grass dominance historically. The AHGA included a comprehensive accuracy assessment using 234 field sampling points in the U.S. portion of the Apache Highlands ecoregion. The overall accuracy rate of the final map was greater than 77%.

The New Mexico Rangeland Ecological Assessment (REA) was limited to southern New Mexico and includes the northeastern portion of the Sky Islands project area. Mapping was completed by 70 experts at approximately 1:23,000-1:100,000 scale. Condition classes in the REA are vegetation states in the state-and-transition models that accompany Natural Resources Conservation Service's ecological site descriptions (NRCS 2009b). REA condition classes are similar to those of the AHGA in that most altered classes reflect increases in woody plant cover over historical condition. However, REA classes are finer-scale, being associated with ecological sites, and stress *relative* rather than *quantitative* woody cover, the distribution of grasses between or under woody plants, grass composition dominated by long-lived perennial grasses versus sparse ruderal perennial or annual species, and non-vegetative indicators such as soil erosion (table 1). The REA did not map non-native grasses, as the spread of Lehmann and Boer lovegrass into southwest New Mexico was limited before

2007 (Gori and Enquist 2003; Schussman and others 2006). The REA did not include an accuracy assessment.

For this analysis, the two assessments were combined into one spatial dataset by grouping the finer-scale REA condition classes up to AHGA classes (table 1). The combined spatial data set does not identify grasslands in Mexico outside of the Apache Highlands ecoregion. To represent these grasslands, we used the Instituto Nacional de Estadística y Geografía (INEGI) land cover map that contains no information on the current condition of grasslands or on the spatial extent of former grasslands. Using the combined data set, we summarized the historical extent and current condition of grasslands and savannas across the project area (fig. 1).

Mapping Sensitive Species and Natural Communities

To assist in the identification and evaluation of Sky Island grasslands, we summarized existing information from a variety of sources on the distribution of sensitive grassland species and riparian-aquatic species that occur in wetland habitats embedded within grasslands (table 2). These species were identified as targets in NFWF's Sky Island Business Plan (NFWF 2009). In addition, we summarized occurrence information for several natural communities that have declined significantly (>90% from historical extent) over the last 100+ years due primarily to human impacts: ciénega wetlands, sacaton riparian grasslands, and Chihuahuan black grama grasslands (Hendrickson and Minckley 1984; Humphrey 1960; Yanoff and others 2008). Occurrence records obtained from the Natural Heritage Programs in Arizona, New Mexico, and Sonora were screened to identify grassland and riparian-aquatic species. Natural Heritage data were not available for Chihuahua.

Table 1—Sky Island Grassland Assessment condition classes and the original AHGA and REA classes.

Original assessment class	Source	Sky Island assessment class
Native grassland and savanna with low woody cover ^a	AHGA	No or low woody increase, native grassland and savanna
Native grassland with or without ruderal grasses	REA	"
Native savanna with or without ruderal grasses	REA	"
Bottomland sacaton (<i>Sporobolus wrightii</i> , <i>S. airoides</i>) grassland	AHGA	"
Woody-invaded native grassland and savanna with medium woody cover ^b	AHGA	Medium woody increase, native grassland and savanna
Woody-invaded native grassland with or without ruderal grasses	REA	"
Woody-encroached native savanna with or without ruderal grasses	"	"
Non-native grassland and savanna with low woody cover, where non-native perennial grasses, Lehmann and Boer lovegrass, are common or dominant ^a	AGHA	No or low woody increase, non-native grassland and savanna
Non-native grassland and savanna with medium woody cover, where non-native perennial grasses, Lehmann and Boer lovegrass, are common or dominant ^b	AHGA	Medium woody increase, non-native grassland and savanna
Former grassland and savanna with high woody cover ^c	AHGA	High woody increase, former grassland and savanna
Woody-dominated former grassland	REA	"
Woody-dominated former savanna	REA	"
Highly eroded former grassland	REA	"
Highly eroded former savanna	REA	"

^aWoody cover < 10%

^bWoody cover 10-35%, with cover of mesquite or juniper, *Prosopis* and *Juniperus*, <15%

^cWoody cover >15% cover mesquite and juniper combined and/or >35% total woody cover; perennial grass cover always <3%; type conversion from grassland or savanna to shrubland.

Table 2—Spatial data collected and data sources for analysis of NFWF target and high-priority grassland and riparian-aquatic species occurrences in priority grassland landscapes.

Biological feature	Data source
Ciénega	Ciénega database and spatial layer developed by TNC-AZ based on literature, agency reports, expert knowledge and field reconnaissance
Sacaton riparian grasslands	Mapped by experts, AHGA (Gori & Enquist 2003; Enquist and Gori 2008) and REA (Yanoff and others 2008)
Black grama grasslands	Mapped by experts: historical extent and current condition on Sandy and Shallow Sandy ecological sites; REA (Yanoff and others 2008)
Black-tailed prairie dog (<i>Cynomys ludovicianus</i>) colonies	Database and spatial layer developed by TNC-AZ based on literature, agency reports & expert knowledge.
Pronghorn (<i>Antilocapra americana</i>)	Spatial layer developed by TNC-AZ & NM based on Brown and Ockenfels (2007), AZGFD (2010) and expert knowledge
Jaguar (<i>Panthera onca</i>)	Spatial layer developed by TNC-NM and AZ based on agency reports and expert knowledge
Bison (<i>Bison bison</i>)	Spatial layer developed by TNC-NM and AZ based on agency reports and expert knowledge
Mexican gartersnake (<i>Thamnophis eques megalops</i>)	Location information cited in Rosen and others (2001)
Sensitive grassland and riparian/aquatic species	Spatial information on species occurrences from Natural Heritage Programs in AZ and NM and Centro de Datos para la Conservación de Sonora; sensitive grassland and riparian-aquatic species and subspecies have global ranks of G1-G3 and T1-T3

Tapping Expert Knowledge to Delineate and Evaluate Highlight Priority Landscapes

In the process of compiling the information above, we recognized that these sources did not fully capture the collective knowledge that we knew to exist for the region. In September 2010, we assembled several experts to both expand our understanding of grasslands across the region and to explicitly delineate focal areas. Participants included: Angel Montoya, Peregrine Fund and Partners for Fish and Wildlife; Dan Robinett, NRCS retired; Miles Traphagen, Turn of The Century Monitoring Inc.; and from The Nature Conservancy: Gita Bodner, Dave Gori, Peter Warren, and Steven Yanoff, assisted by Anne Bradley and Lara Miller.

Participants were asked to map areas they viewed as particularly promising for sustaining the region's grasslands over the long term, drawing on their own knowledge and a variety of supporting information provided at the workshop. We seeded the discussion with suggested criteria for identifying, delimiting, and evaluating "priority grassland landscapes" and with polygons used in the NFWF Business Plan (NFWF 2009), but participants were free to map and describe attributes of these delineated areas as they saw fit. Suggested criteria included size of grassland blocks, ecological condition of those blocks, presence of embedded streams and wetlands and target wildlife species, fragmentation versus connectivity of grassland habitat and of native vegetation more broadly, presence of intractable threats, and existence of conservation efforts such as local community partnerships. Spatial data sets provided to participants included information on vegetation classifications, AHGA and REA grassland condition assessments, soil classifications, species occurrence locations and habitat models, land protection status, and results of various groups' efforts to identify priority conservation areas for other purposes. Once polygons were drawn and met with group agreement, participants were asked to fill out a matrix of conservation value and feasibility for each. Criteria evaluated included many of the same ones used to inform the drawing of the polygons, but this exercise required participants to rate criteria for each site as low, medium, or high and,

where necessary, explain those ratings. This was done as a group effort, with discussion of rankings along the way. Filling out the matrix together also spawned discussions about the characteristics of each grassland landscape, and about additional sources of information about distributions of target species and communities.

Results and Discussion

Hereafter, we will refer to "grasslands and savannas" collectively as "grasslands" to streamline the presentation and discussion of results.

Historic Distribution and Current Condition of Sky Island Grasslands

Experts in the United States and Mexico identified 13,902,000 acres as current or former grassland, which corresponds to almost half of the area we analyzed (table 3; fig. 1). We assume that this represents a conservative figure for the historic distribution and extent of grasslands in this area. Furthermore, grasslands were highly connected historically, allowing wide-ranging species, like bison, pronghorn, and grassland birds, as well as species with more limited dispersal capabilities, like black-tailed prairie dogs, to move freely within and between these habitats.

Only 2.6 million acres or 18.9% of these grasslands are currently dominated by native grasses and relatively open and shrub free. By comparison, shrub encroachment has occurred on over 8,159,000 acres or 58.7% of current and former grasslands. Approximately 4.9 million acres or 35.1% of current and former grasslands have experienced more shrub encroachment but still fall into classes where this change is considered reversible, for example, with prescribed fire or other brush control methods. However, shrub cover and associated soil erosion has exceeded a threshold on over 3.2 million acres, producing a type conversion from grassland to shrubland on almost one quarter of the historic grasslands and savannas in this region. Such areas are considered difficult if not impossible to return to open grassland states

Table 3—General statistics for grasslands (U.S. and Mexico) in the Sky Island region.

Grassland type	# Patches	Total acres	% All grasslands
No or low woody increase, native grassland	102	2,144,488	15.4
No or low woody increase, native savanna	48	478,953	3.5
Medium woody increase, native grassland and savanna	138	3,212,191	23.1
No or low woody increase, non-native grassland and savanna	11	162,417	1.2
Medium woody increase, non-native grassland and savanna	19	1,342,952	9.7
High woody increase, former grassland and savanna	185	3,275,463	23.6
Mix of low and medium woody increase, native grassland and savanna	26	328,574	2.4
Undetermined grassland and savanna	5,764	2,956,650	21.3
Total U.S.-MX Grassland/Savanna		13,901,688	

on any substantial scale, though small patches might conceivably be recovered with heavy investment of resources.

The spread of non-native perennial grasses within grasslands has also been substantial (table 3). Boer lovegrass and, to a greater extent, Lehmann lovegrass are common or dominant on at least 1.5 million acres such that non-native grasslands with little to moderate woody increase comprise 11% of this area's current and former grasslands. When the AHGA was completed in 2003, non-native grasslands were largely restricted to Arizona. However, Lehmann lovegrass appears to be spreading into southwestern New Mexico as it is now present in long-term monitoring plots where it had not previously been recorded (P. Sundt 2009). Implications of this spread are mixed, with some wildlife species more impacted than others (Bock and others 1986; Albrecht and others 2008). Native grasses remain present in many invaded areas, albeit at lower density. Fire regimes and hydrology can be affected but are not as radically transformed as in the case with many plant invasions (Emmerich and Cox 1992).

Identification, Delineation, and Evaluation of Priority Landscapes

Participants largely agreed on locations of “best” remaining grassland landscapes (fig. 2). Polygon boundaries were adjusted based on additional knowledge about locations of valued features (e.g. extending the Janos polygon north into the Playas Valley to reflect movements of a wild bison herd) or ongoing conservation efforts (e.g. expansion of Muleshoe-Aravaipa polygon to include an area known as the Bonita grassland where landowners are combating shrub invasion). Experts suggested addition of polygons (e.g. Buenaventura) to incorporate areas that met many of the suggested criteria but whose values have not been widely known among practitioners in this region. The group also recommended dropping two polygons (Santa Cruz and San Pedro-U.S.) that had been previously delineated but rated low in grassland-specific values (table 4). Both areas continue to harbor other habitats of high conservation value, particularly riparian systems, which may in turn benefit from grassland restoration activities. Nevertheless, for the purposes of grassland conservation per se, these areas were seen as being less likely than other landscapes to host large blocks of grassland habitat into the future. Parts of the initial Santa Cruz polygon that still have substantial grassland patches were added to the Altar Valley polygon, with which experts identified relatively high landscape connectivity (an impression substantiated by the multi-year movements of a wandering jaguar known as Macho B). In two cases,

participants chose to further refine polygon boundaries by examining additional information after the workshop. Overlaying draft polygons on Google Earth proved especially useful for modifying boundaries to exclude highly modified areas such as center-pivot agriculture in Chihuahua.

The 12 final polygons incorporated almost all the substantial blocks of highest-quality grassland that the condition assessments had identified within the region (83% of overall acreage in native no-to-low woody increase classes) as well as substantial acreage of surrounding patches deemed restorable grassland (fig. 2). These polygons also succeed at encompassing many of the other target biological features associated with grasslands (fig. 3, table 5). For example, all but two riparian sacaton grassland patches identified in grassland assessments were included in final polygons. The two that were not identified are relatively isolated from other grassland blocks, one being on the southwestern edge of the region where terrain changes to highly dissected Sonoran scrub, and the other being on the northern end where terrain rises towards the Mogollon Plateau. The latter is near the Burro Cienega-Hachita polygon but is separated from it by a large open pit mine.

Delineations of these major grassland landscapes largely conformed to units defined by individual valleys. This evaluation bore out previous observations that the largest remaining blocks of open grassland tend to be in mid-elevation valley bottoms (e.g. San Rafael, Empire-Cienega-Sonoita). Grassy hills contribute substantial blocks in some areas (e.g. Tumacacori and Sierrita portions of the Altar polygon). In others (North Peloncillos, Southern Sulphur Springs, Aravaipa-Muleshoe-Willcox), grassland habitat primarily occurs on bajada or foothills terrain above lowlands that have undergone vegetation and/or land use conversions. We applied the valley names most commonly used by local communities to refer to these grassland landscapes. Participants discussed combining nearby polygons but decided that the smaller units more accurately reflect differences among nearby polygons in enabling conditions, e.g. in community culture or development threats among nearby polygons.

In filling out the evaluation matrix for these polygons, participants largely agreed on ratings (table 4). Where there was initial disagreement, further discussion was usually enough to bring the group to consensus on a final rating. One exception came in trying to rate an aspect of conservation feasibility that reflects the influence that active community and partner groups have by promoting and/or implementing conservation measures in a given landscape. Participants agreed on the importance of this factor, discussed activities of various partner

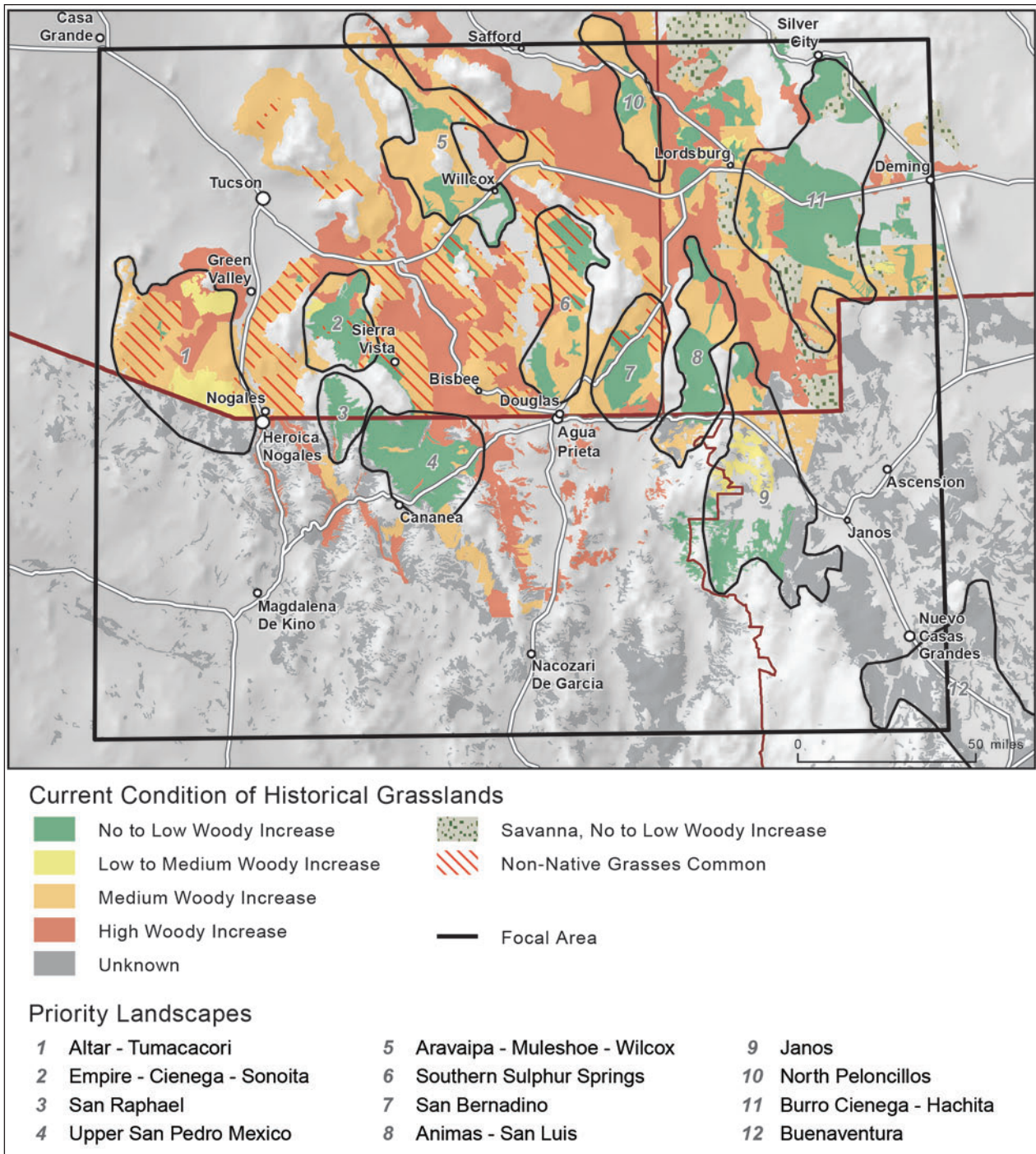


Figure 2—Priority grassland landscapes, showing ecological condition.

groups and modified some polygon boundaries to reflect partner work, but ultimately decided that this factor could not be readily distilled into a comparative rating. In all areas, participants recognized that (1) additional information or increased conservation efforts could change these ratings, (2) that all 12 polygons hold substantial promise for conservation of grasslands and associated species, and (3) that both opportunities and needs vary among the set.

Discussion among participants also drew out observations about a number of ecological gradients present across the region, added to information on target species, described both threats and conservation

values of particular landscapes in greater detail, and added information about partners and their conservation activities (elaborated in Gori and others 2012).

Applications for Protection and Restoration

In each of these landscapes, successful grassland conservation will need to include three key components: (1) strong partnerships within the local community, which in turn support, (2) land protec-

Table 4—Conservation value and feasibility of success for Sky Island grassland landscapes.

Grassland conservation value												
Landscape name	Altar-Tumacacori	Empire-Cienega-Sonoita	San Rafael	Upper San Pedro Mexico	Aravaipa-Muleshoe-Wilcox	Southern Sulphur Springs	San Bernardino	Animas-San Luis	Janos	North Peloncillos	Burro Cienega-Hachita	Buenaventura
Polygon map #	1	2	3	4	5	6	7	8	9	10	11	12
Intact landscape												
Size of potential grassland block	High	High	Med	High	High	Med	Med-high	High	High	Low	High	High
Connectivity* across single valley	High	High	High	High	Med	Low	High	High	High	Med	High	High
Connectivity* with other grassland landscapes	Med-low	High	High	High	Med-low	Low	High	High	High	Med	Med	High
International connectivity, north-south	High	Med-low	High	High	Low	Low	Med	High	High	Low	High	Med-low
Existing habitat quality												
Grassland	Med	High	High	Med-high	High	Med	High	High	High	Med-high	Med-high	High
Riparian grassland	Med-high	High	High	High	Med-high	Med	Med	High	Med	Low	Med	?
Associated wetland habitats	High	High	High	High	High	Med-high	High	High	Low	Low	Med-high	Med
Summary rating	29	32	33	34	25	17	30	35	29	17	29	31
Conservation Feasibility												
Progress to date												
Land protection	High	High	High	Low	Med	Med-low	Med-high	High	Med-high	Med	Med-low	Low
Ecological land management	High	High	Med-high	Low	Med	Med-low	High	High	Low	Low	Med	Low
Intractable threats												
(low = 5)	Med	Med	Low	Med	Med	Med	Low	Low	Med	Low	Low	Med
Summary rating	13	13	14	5	9	7	14	15	8	9	10	5
High = 5, Med-high = 4, Med = 3, Med-low = 2, Low = 1												

Ranking Criteria based on size, condition, conservation importance of species present, landscape context. See Gori et al. 2012 for descriptions of embedded wetlands considered in ratings, descriptions of threats, names and selected activities of known partners active in each landscape.

Shading indicates adjacent landscapes that experts considered merging but chose to instead identify as complexes. *Connectivity ratings here are based on proximity of grassland blocks with one another via areas of similar grassland habitat; this is meant to reflect how grassland-obligate, terrestrial animals such as pronghorn would perceive connectivity. For species that readily travel across non-grassland natural habitats such as forests or scrublands, these connectivity ratings could be considerably higher.

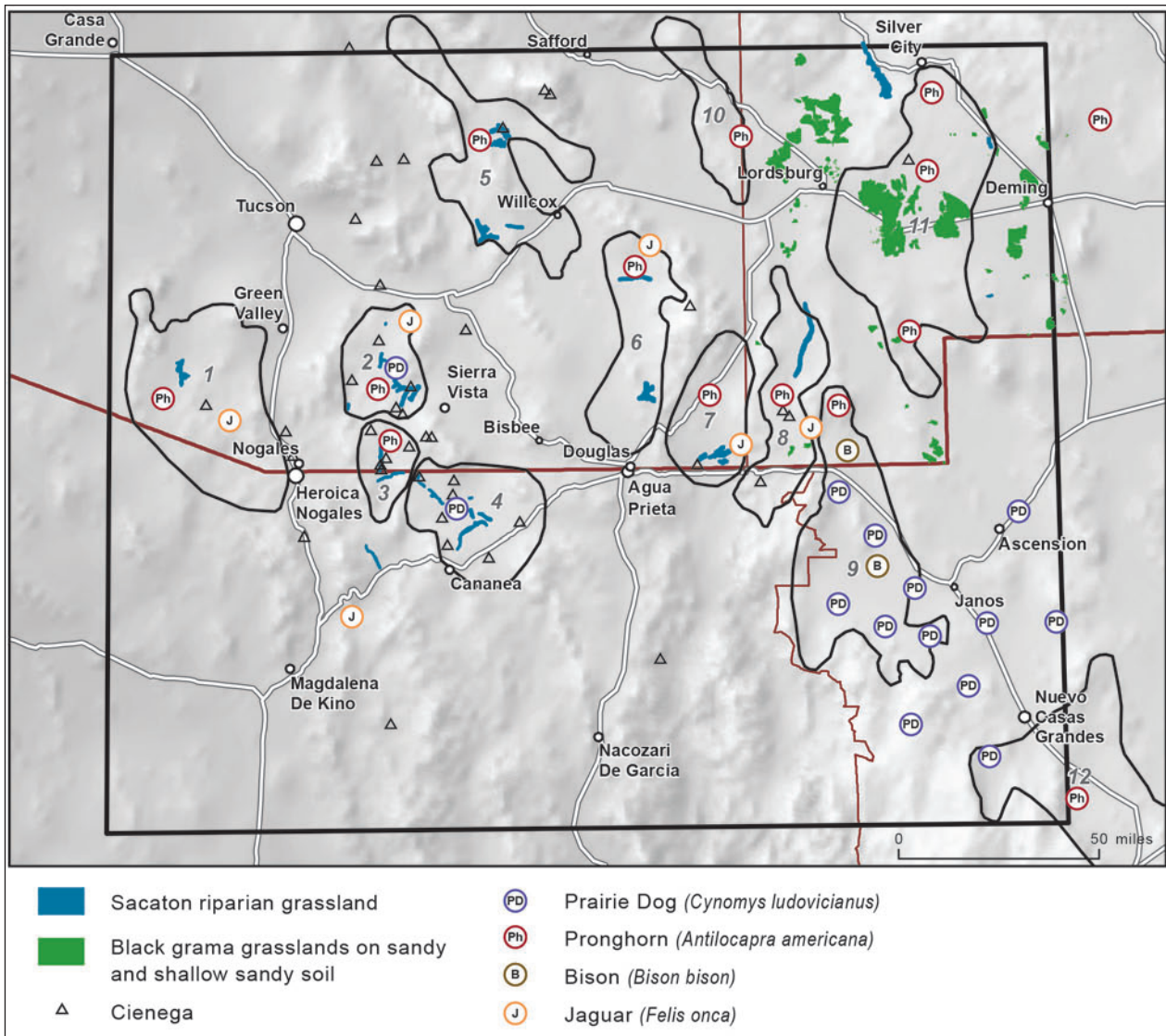


Figure 3—Priority grassland landscapes, showing select species and biological features of interest.

tion to prevent further fragmentation of the surviving grasslands, and (3) active ecological management to restore and maintain grassland health through time. These are addressed further in Gori and others (2012), highlighted below to show the broad utility of information presented here.

Overlaying polygons on land management highlights the role of particular institutions in sustaining grasslands across the region and within each individual landscape. For instance, these maps suggest that if the U.S. Forest Service wants to invest in maintaining open grasslands, this agency might focus on areas within the San Rafael polygon; if the agency’s goal is to restore recoverable grassland, working in the Altar-Tumacacori might provide the best opportunities. Of federal agencies, BLM has a particularly large role to play across the U.S. portion of this region. While each of these landscapes includes a mix of public and private lands, success in landscapes like the Empire-Cienega-Sonoita depends heavily on management

effects on BLM lands. By contrast, outcomes in landscapes such as the Animas-San Luis Valley depend almost entirely on the actions of private landowners.

Comparing polygons to maps of land management and protection status (Gori et al 2012) highlights places where grassland blocks are vulnerable to fragmentation by human infrastructure and disturbance, as well as key opportunities to protect long term connectivity of natural vegetation for the many wildlife species that are affected by more dramatic landscape changes such as proliferation of roads, houses, mines, or intensive agriculture. Several jurisdictions, for instance, combine to provide protection across nearly the entire San Rafael Valley in the United States; adding easements or other conservation status to the last remaining large block of unprotected private land at the top of the valley would secure the ongoing value of these previous investments. Successfully completing long-standing efforts to bring publicly identified parcels of Arizona State Trust land into

Table 5—Species of concern identified in NFWF (2009) that occur in priority grassland landscapes. Target species are designated as Type = A, and high-priority species likely to benefit from grassland conservation and restoration as Type = B. An "X" indicates that species has been recorded at the site. Data used to populate the table came from Natural Heritage Program (NHP) databases for Arizona, New Mexico and Sonora, gray-literature reports, and expert knowledge. Six species on NFWF's list were not included in the table because NHP is not tracking them and summary information from other sources was not readily available. In general, the lack of records for a species at a site may not mean that the species is absent but may be a function of insufficient survey effort.

Common Name	Type	A-T	EV-S	SR	U.SP	Priority Grassland Landscape ^a							NP	BC-H	BV
						A-M-W	S.SS	SB	A-SL	PV-JP	NP	BC-H			
Jaguar	A	X	X							X					
Bison	A									X				X	
Pronghorn	A	X	X	X						X			X	X	
Black-tailed prairie dog	A		X		X					X			X	X	
Chiricahua leopard frog	A	X	X	X	X					X			X	X	
Aquatic Amphibians & Reptiles															
Sonoran tiger salamander	B			X	X										
Lowland leopard frog	B	X	X	X						X					
Mexican garter snake	B	X	X	X						X					
Native Fish															
Gila topminnow	B	X	X	X										X	
Gila chub	B			X											
Yaqui topminnow	B			X						X					
Yaqui chub	B			X						X					
Yaqui catfish	B			X						X					
Mexican stoneroller	B			X						X					
Yaqui longfin dace	B			X						X					
Beautiful shiner	B			X						X					
Gila longfin dace	B	X	X	X	X										
Desert sucker	B		X	X											
Sonoran sucker	B	X	X	X											
Desert pupfish	B		X	X											
Sonora chub	B	X													
Priority Landscapes^a															
Common Name	Type	A-T	EV-S	SR	U.SP	A-M-W	S.SS	SB	A-SL	P-JP	NP	BC-H	BV		
Roundtail chub	B					X									
Spinedace	B					X									
Loachminnow	B					X									
Speckled dace	B		X			X									
Grassland Reptiles															
Desert massasauga	B						X	X							
Grassland Birds															
Aplomado falcon	B								X				X		
Grasshopper sparrow	B	X	X	X	X		X	X	X	X					
Baird's sparrow	B	X	X	X				X	X	X					
Western burrowing owl	B			X		X			X	X					
Mammals															
White-sided jackrabbit	B								X				X		

^aPriority landscape abbreviations are: A-T = Altar Valley-Tumacacori; E-C-S = Empire-Cienega-Sonora; SR = San Rafael Valley; U.SP = Upper San Pedro, MX; A-M-W = Aravaipa-Muleshoe-Willcox; S.SS = Southern Sulphur Springs Valley; SB = San Bernardino; A-SL = Animas Valley-Sierra San Luis; P-JP = Playas Valley-Janos Plains; NP = Northern Peloncillos; BC-H = Burro Cienega-Hachita; BV = Buenaventura.

conservation status would greatly benefit five of the 12 priority grassland landscapes identified here. Conserving these State Trust lands would, for example, safeguard the grassland block in the center of the Empire-Cienega-Sonoita, and secure wildlife connectivity across the I-10 corridor, Catalina-Rincon Mountains, and the San Pedro River to the Aravaipa-Muleshoe-Willcox landscape.

Overlaying polygons on maps of grassland habitat condition highlights key opportunities to protect or restore connections for species such as pronghorn whose movements are affected by habitat changes such as shrub encroachment (Brown and Ockenfels 2007). However, for planning and implementing restoration or management interventions, more information is needed. Closer examination of Ecological Site maps (Bestelmeyer and others 2009) can provide many insights into conservation value and management options within landscapes. Finer-scale mapping of ecological condition (e.g. by ecological state) can then inform selection of project locations, treatment methods, and monitoring (Tiller and others 2012).

Future efforts to gather information from additional experts would no doubt improve the resolution, accuracy, and richness of the regional picture presented here. We recognize, for example, that challenges of collecting data across state and international boundaries create inconsistent coverage for some communities and species, and welcome refinements. The large proportion of grasslands in Mexico currently depicted as “unknown condition,” for example, highlights the need to compile consistent information about these areas. We encourage readers to treat this assessment, and others like it, as living documents to be modified and added to as time goes on, as ecological and social conditions change, as species ranges shift, and as we learn more about all these factors.

In reviewing the status and trends of Sky Island grasslands, it is clear that maintaining them as functioning systems represents one of the greatest needs, and greatest challenges, of any conservation issue in the borderlands. These grasslands are an essential link that sustains the wildlife in the mountains and the perennial waters in the valley bottoms. Yet successful grassland conservation is complex, requiring simultaneous progress on several fronts: protecting the land from fragmentation, managing the land to control shrubs and maintain grass cover, and supporting community organizations and other partnerships that get the work done. We hope that this analysis, combined with efforts to make progress on these fronts and evaluations of what is working best, helps us all rise to this challenge.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Sacaton Riparian Grasslands of the Sky Islands: Mapping Distribution and Ecological Condition Using State-and-Transition Models in Upper Cienega Creek Watershed

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Abstract: Riparian grasslands dominated by *Sporobolus wrightii* (big sacaton) were once widely distributed in the intermountain basins of the Madrean Archipelago. These alluvial grasslands are still recognized as key resources for watershed function, livestock, and wildlife. The upper Cienega Creek watershed in SE Arizona is thought to harbor some of the region's most extensive sacaton stands. Documenting their extent and ecological state is important for informing management in this valley and for contributing to a clearer picture of this community's status across the region. Our objectives were to map the distribution of sacaton; qualitatively assess stands of sacaton into ecological states; and test mapping and assessment methods for use in other valley bottoms in the region. We used a two-step approach: interpretation of aerial photography and soil maps followed by field reconnaissance. Field work consisted of qualitative, rapid assessments of ecological state using the Natural Resource Conservation Service's State-and-Transition (S&T) models for the Loamy Bottom Ecological Site. The most open and productive state of Sacaton Grassland occupies 54 percent of alluvial habitats evaluated, with remaining acreage in various states of degradation, recovery, or transition to Mesquite Bosque woodland. Our observations in the Cienega Creek watershed suggest potential modifications to the S&T models that may more accurately reflect site potential, likelihood of transitioning to other states, and management strategies tailored to maintaining or improving sacaton grassland conditions across the region.

Introduction and Rationale

Riparian grasslands dominated by big sacaton (*Sporobolus wrightii*) once formed nearly pure stands of robust perennial grass along the Southwest's perennial and intermittent streams (Bahre 1991; Brown 1982; Humphrey 1958). The sacaton riparian habitat is distinct from, yet shares features with, neighboring riparian habitats and upland grassland associations. Individual plants and small clumps of this grass can be found in many settings. In the right soils and alluvial settings, however, big sacaton, and to a lesser extent alkali sacaton (*S. airoides*), creates a unique habitat formation sometimes called a sacaton "flat" or "bottom" with distinct history and management needs. Developing maps of sacaton grassland extent and ecological condition can provide a foundation from which to develop informed management objectives and actions that maintain, restore, and promote the resilience of this important community.

Historical Geography

Declining Distributions

Sources estimate sacaton grasslands now occupy less than 5 percent of their original distribution across the region (Humphrey 1960).

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Commonly cited causes of decline include natural phenomena and anthropogenic influences from as early as the late 1800s (Cooke and Reeves 1976; Cox and others 1983; Humphrey 1958, 1960). With channel entrenchment, reductions in overbank flooding, and the advent of industrialized farming, vast expanses of *Sporobolus* grassland became ideally suited for agriculture and many thousands of acres were converted to crops by the mid-1900s.

Current Geography and Condition

Despite steep declines, stands of bottomland sacaton grassland are still found scattered across their former range with the larger, more intact examples most recognizable. Fine stands of big sacaton grasslands can still be found in upper reaches of gently sloping valleys like the upper Cienega Creek basin, upper Babocomari River, upper San Pedro River in Mexico, and upper Santa Cruz River basin near Lochiel. Condition of sacaton flats in the region varies widely from mature stands surviving on eroded former floodplain terraces or under the canopy of mesquite woodlands, to exceptionally productive stands with little bare soil or woody cover between plants that exceed 6 ft. in height.

These stands are recognized as key resources for watershed function, livestock, and wildlife and there is a growing interest in their conservation and management in Arizona. In the past 30 years, large-scale riparian conservation areas have been established within several watersheds that harbor extensive sacaton flats. Some of the finest remaining examples exist on the Las Cienegas National Conservation Area (LCNCA) managed by the Bureau of Land Management (BLM). The BLM is responsible for this and other conservation areas and has been particularly active in seeking direction regarding the status of these grasslands and guidance for management.

Limited efforts have been made to map the contemporary distribution of sacaton and associated communities in the Sky Island region. These vary in their spatial extent and the degree to which they treat sacaton flats as a distinct entity (table 1). We know of no efforts, however, that systematically evaluate ecological condition of sacaton grasslands in a focal watershed, let alone the region. Our case study examined alluvial habitats on the upper Cienega Creek watershed (fig. 1) to (1) map the distribution of bottomland sacaton stands in the study area; (2) qualitatively assign sacaton stands into ecological states to understand dynamics and inform management; and (3) test methods for mapping and evaluating sacaton communities elsewhere.

Methods

This mapping effort followed a framework laid out by the Natural Resources Conservation Service (NRCS), first mapping distribution of plant communities associated with particular soil and climate settings (Ecological Sites) (Briske and others 2006) and then mapping “states” or ecological condition within those (Bestelmeyer and others 2010). To map sacaton bottomlands, we used a two-step approach: interpretation of aerial photography and field reconnaissance. In preparation for fieldwork, we digitized provisional polygons based on aerial photos using three pieces of GIS information in ArcMap 10: (1) BLM’s layer of ecological sites mapped by NRCS specifically for

Las Cienegas (BLM 2003); (2) county soil maps and ecological sites NRCS associated with these soils (soildatamart.nrcs.usda.gov); (3) and, aerial photographs from the USDA’s 2007 National Agricultural Imagery Program (NAIP; datagateway.nrcs.usda.gov). The first two layers guided our focus on alluvial soils capable of supporting bottomland sacaton stands (fig. 1). The third layer provided 1-m (3-ft.) resolution, 4-band digital aerial photographs. With the near infrared band expressed to provide greater differentiation of features, we drew polygons based on color, texture, and vegetation differences apparent across the alluvial ecological sites. Some polygons extended beyond soil map units to capture the full extent of target plant communities.

Field verification focused on areas with greatest concentration of sacaton grasslands (fig. 2). Using handheld GPS units (Trimble Juno SB) equipped with GIS (ArcPad 8), ground-level information was recorded at one or more locations within a polygon depending on the homogeneity or variability apparent between field maps and on-the-ground observations. Polygons were adjusted as necessary where sacaton stretched beyond or compressed within the boundaries of digitized projections. Unique features within a polygon were also catalogued. These included erosional features and other plant associations (e.g., tobosa or blue grama grasslands, cottonwood-willow forest, and rabbitbrush (*Ericameria* scrublands).

To evaluate current condition of sacaton stands in the field, we used rapid-assessment qualitative descriptions of habitat type, marked GPS

Table 1—Other vegetation mapping efforts with a variety of purposes and spatial extents that included upper Cienega Creek watershed.

Agency	What and where they surveyed	What they found in Cienega watershed
The Nature Conservancy (Gori and Enquist 2003)	Regional grassland condition survey combining expert knowledge and field reconnaissance.	723 acres of sacaton riparian grassland without condition evaluations.
Bureau of Land Management and NRCS (BLM 2003)	Empire and Empirita allotments and Las Cienegas NCA. Includes Cienega Creek and tributaries in an ecological site map for Las Cienegas.	7,600 acres we could classify as alluvial for ecological sites: Loamy Bottom, Sandy Bottom Swale, and Loamy Swale.
AZ Game and Fish Dept. (Kubly and others 1997)	AZ statewide riparian vegetation along the then-known extent of mapped perennial streams.	71 acres of sacaton, 384 acres of mesquite woodland.
USGS, AZ GAP vegetation mapping (Halvorson 2002)	AZ statewide riparian and upland vegetation communities; Cienega Creek, Empire Gulch, Gardner Canyon, and substantial upland areas outside of sacaton-dominated associations. This survey extended beyond strictly riparian stands.	4,680 acres of sacaton-scrub grassland
Pima County (Harris 2000)	Riparian communities within Pima County; included portions of Cienega watershed.	9,290 acres of semi-desert grassland (sacaton and upland together BLP series 143.1; Brown and others 1979), 427 acres of mesquite bosque (series 224.52), and 149 acres of abandoned agricultural fields (presumably mixed former sacaton and cienega habitats).
Pima County, aerial reconnaissance (Fonseca 2000)	Pima County, including upper watershed of Cienega Creek beyond its borders into Santa Cruz County, and sites in Altar Valley, sacaton focus.	732 acres of sacaton grassland communities discriminated from upland grasslands, 2,909 acres of mesquite-sacaton association, and 971 acres of cottonwood-willow forest-sacaton association.

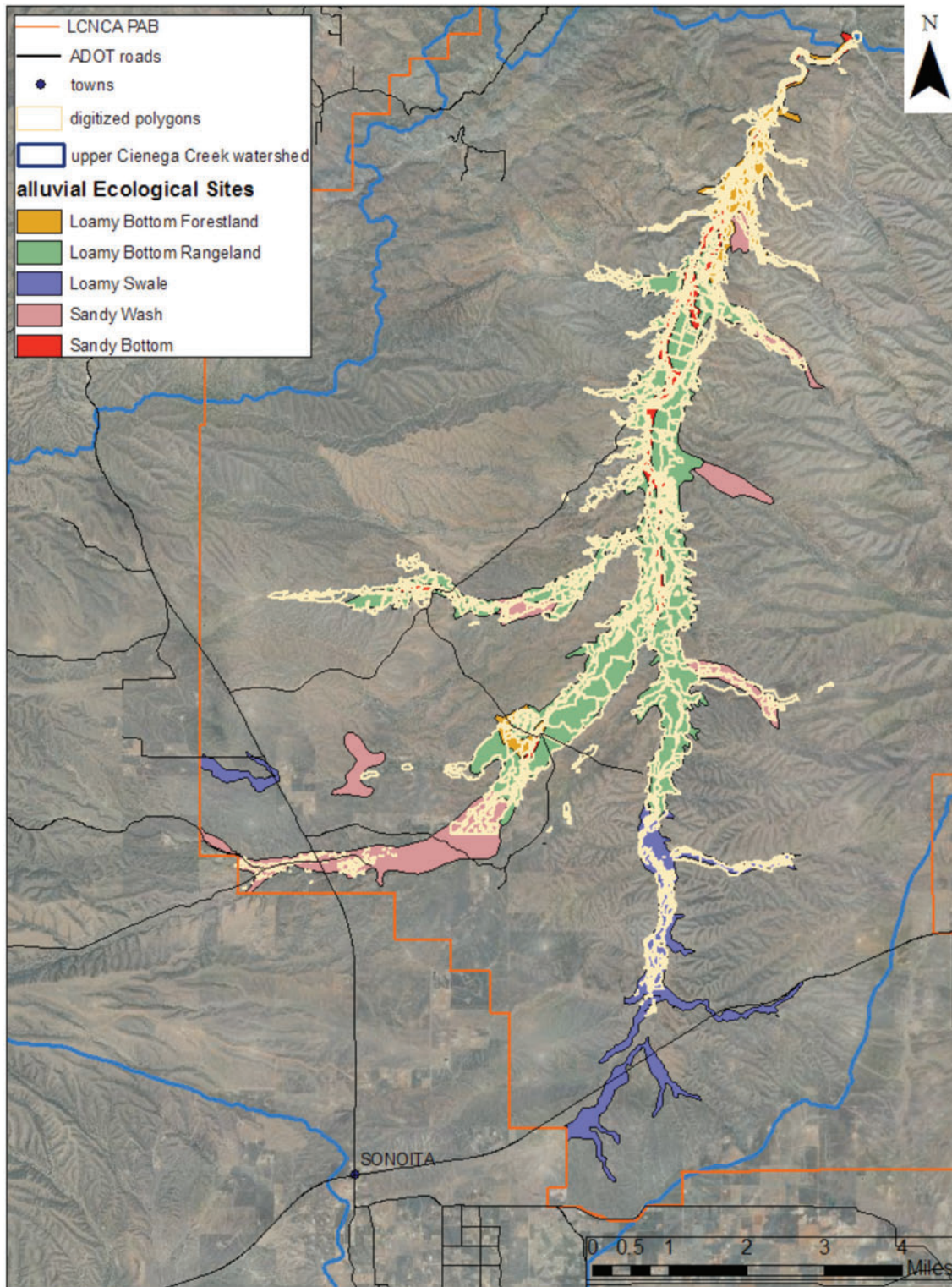


Figure 1—Areas of prospective sacaton grassland and mesquite bosque habitat in upper Cienega Creek watershed (beige lines), digitized from 2007 NAIP aerial imagery. These provisional stands are shown superimposed on alluvial Ecological Sites (colored polygons) previously mapped by NRCS and BLM.

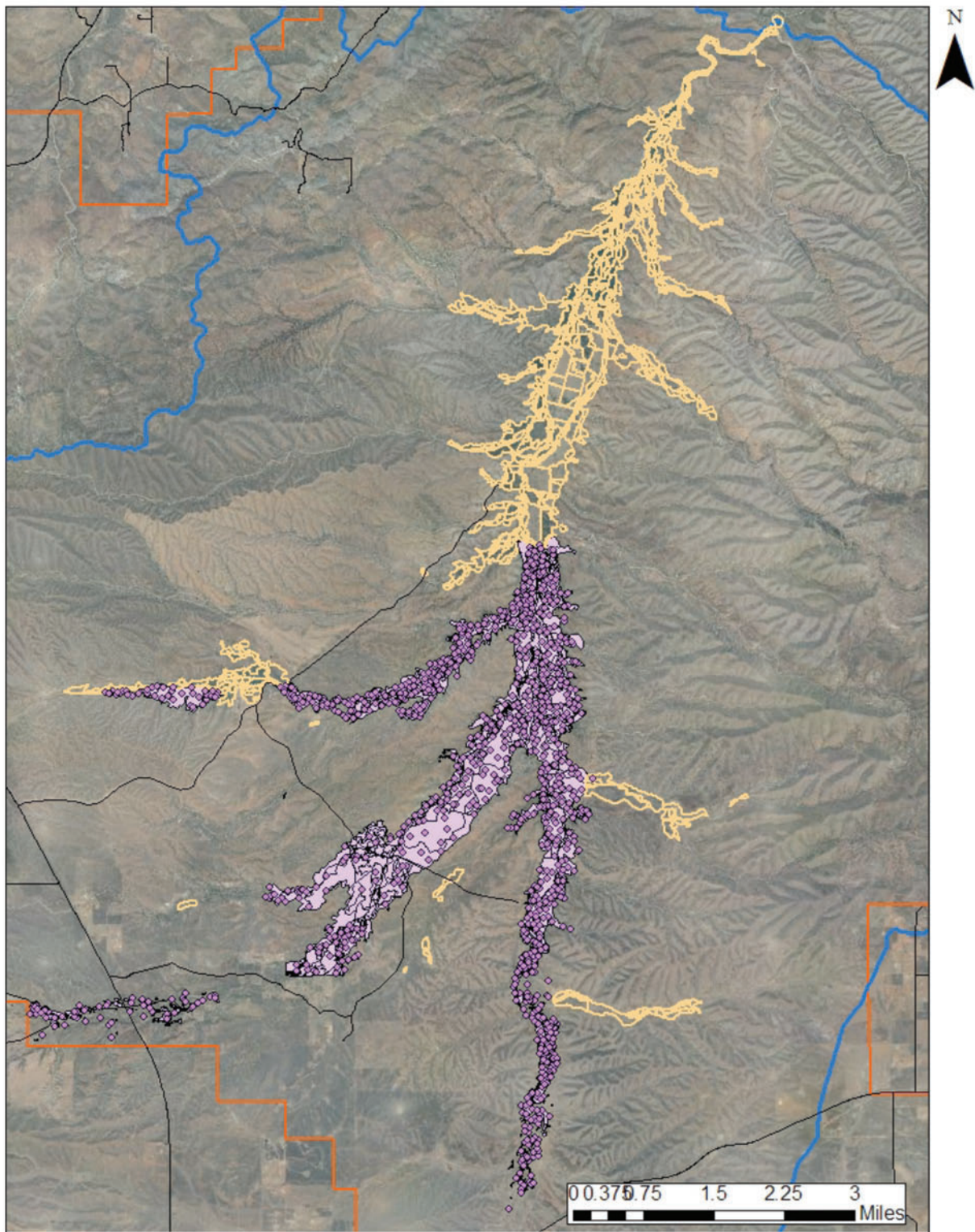


Figure 2—Field verification of extent and condition: Lavender polygons represent areas field-verified and classified according to ecological condition as of September 2011. Purple dots illustrate point locations where field notes were recorded and voucher photographs of features and ecological condition were taken. This field work covered 3,732 acres of alluvial habitats in 560 polygons.

points, snapped voucher photographs, and assigned state categories based on visual estimates of the following: sacaton grass cover (both *Sporobolus* species were treated as equals), woody plant cover (mesquite and other species), evidence of erosion, and mechanisms affecting change (e.g., fire/drought, gully erosion, agricultural conversion) (table 2). Ecological condition categories corresponded to states initially described in the NRCS Loamy Bottom Rangeland State-and-Transition (S&T) models (rangeland: R041XC312AZ and (forestland: F041XC310AZ). However, to more accurately reflect what we found on the ground, we concluded it would be necessary to refine this model by splitting certain states into phases or sub-states to reflect different site potential, likely transitional pathways, and need for more specific prospective management strategies (fig. 3).

Results

Reviewing aerial imagery and soil data yielded 6,563 acres of alluvial ecological sites with potential sacaton or mesquite bosque communities. We field verified 3,874 acre of this digitized area (figs. 2 and 4). Of the area found to be sacaton rangeland, 72 percent had

previously been mapped as Loamy Bottom rangeland, 3 percent Loamy Bottom forestland, 5 percent as Loamy Swale, and 8 percent as Sandy Wash (R041XC316AZ). The remaining areas consisted of upland soils (7 percent) and Sandy Bottom (5 percent; cottonwood-willow forest; F041XC317AZ).

The more straightforward areas to delineate were core alluvial habitats where sacaton or mesquite communities traversed floodplains from side to side. The more difficult boundaries to outline were those at the upper limits of sacaton distribution along the main stem of Cienega Creek and its tributaries. In these areas, sacaton grassland generally transitioned to *Bouteloua gracilis* (blue grama) or *Pleuraphis mutica* (tobosa grass) grasslands in areas with finer surface soils, or to xeroriparian habitats in areas with coarser soils (alluvial fans and washes). At these outer reaches we made the greatest adjustments to the final boundaries of sacaton and mesquite bosque habitats once they were field verified.

Field surveys enabled us to classify point locations and full polygons into states as shown in figure 5. Sample photographs are included in figure 6. USDA, NRCS=S&T models were helpful for assigning states to rangelands/forestlands, but not all of our observed areas fell within

Table 2—Combined Loamy Bottom Ecological Sites (rangeland and forestland), 12-16 inch precipitation zone, in tabular format for quick field reference. Letters represent original models' states; numbers represent revised model's sub-state distinctions. An asterisk (*) denotes naming convention differs from Mesquite-Sacaton state described in Loamy Bottom rangeland S&T model.

Rangeland							Forestland				
State	Sacaton Grassland (HCPC)	Sacaton Grassland	*Sacaton-Mesquite	Exotics	Eroded Sacaton	Eroded Annuals	Eroded Mesquite	Mesquite Bosque-native annuals (HCPC)	Mesquite Bosque - exotic annuals	Mesquite Thornscreb	Mesquite Scrubland
Original state	A	B	C	D	E	F	G	H	I	J	K
Refined sub-state	B1,B2,B3		C1,C2		E1,E2		[not observed]				
	Canopy cover (%)						Canopy cover (%)				
Sacaton	25-80	25-65	5-40		20-50		trace				
Mesquite		1-15	5-20	0-15			20-80	25-65; large	20-80; large	5-20; shrubby	5-20; shrubby
Other shrubs, succulents			yes			0-10	0-10	0-5		5-15	5-15
Exotics (johnsongrass, bermuda)					yes						
Annuals	0-20					yes			yes; dominate	yes; fluctuate	yes; fluctuate
Gully erosion					severe		severe	yes	yes	yes	yes
Flooding					reduced	reduced	no flooding	no flooding	no flooding	no flooding	no flooding
Water table (ft)	<20	<20	<20	<20	>20	>20	25-50	25-50	25-50	25-50	>60
Causal Mechanisms			plowing, cultivation, lack of burning fire		gully erosion	plowing, cultivation, burning low SM			lowered water table		

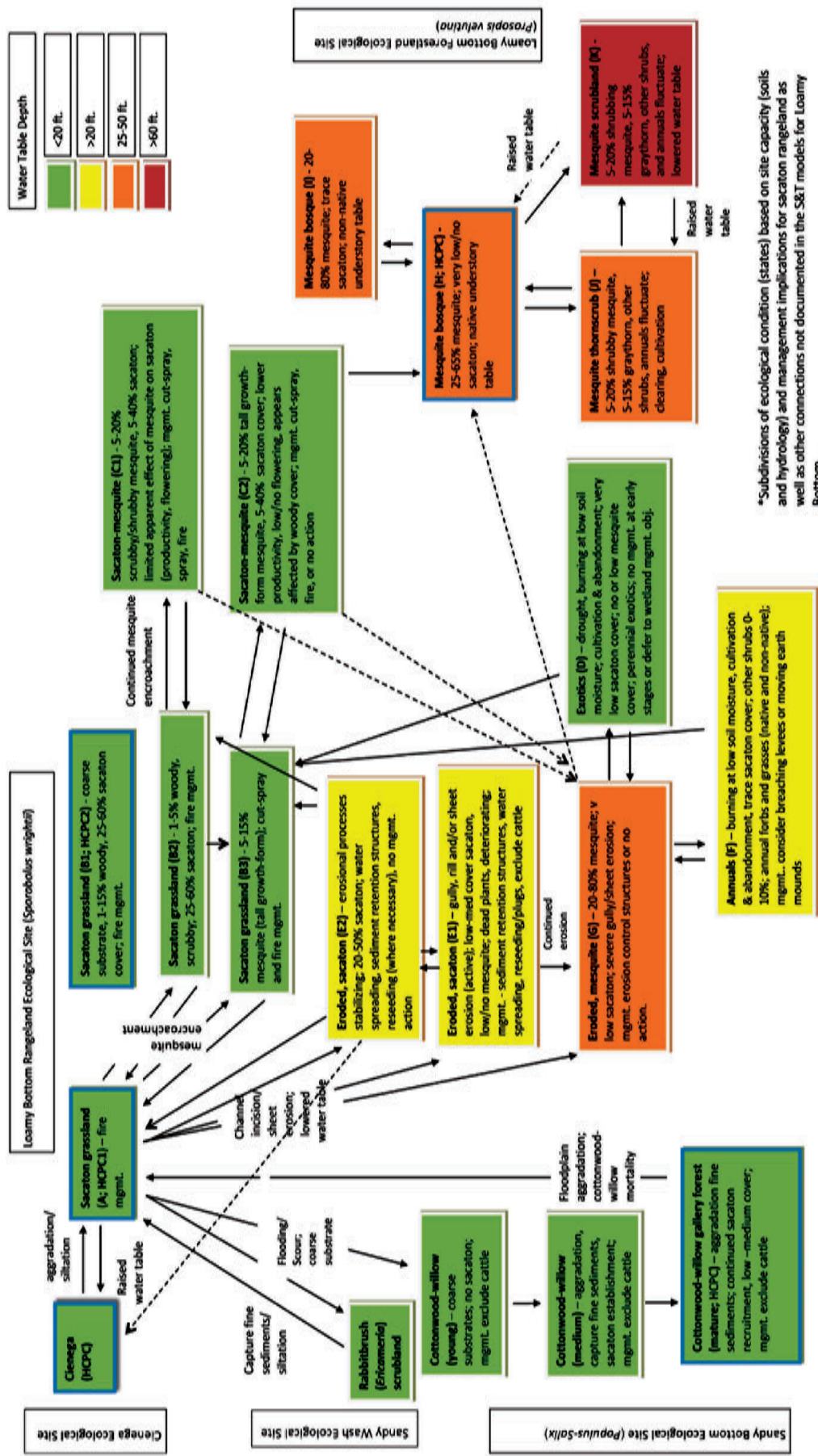


Figure 3—Modified State-and-Transition model for MLRA 41-3 Loamy Bottom Ecological Sites (12-16 inch precipitation zone) based on observations at Las Cienegas National Conservation Area. Our subdivisions of NRCS's states are based on site capacity (soils and hydrology), divergent ecological dynamics, and on management implications for sacaton rangeland. This model also documents several connections among alluvial ecological sites, with transition pathways that are not well illustrated in the NRCS S&T models for Loamy Bottom. Note, for example, the transitional pathways that can transform a sacaton grassland into a mesquite bosque, both of which are highly prized by land managers and wildlife alike.

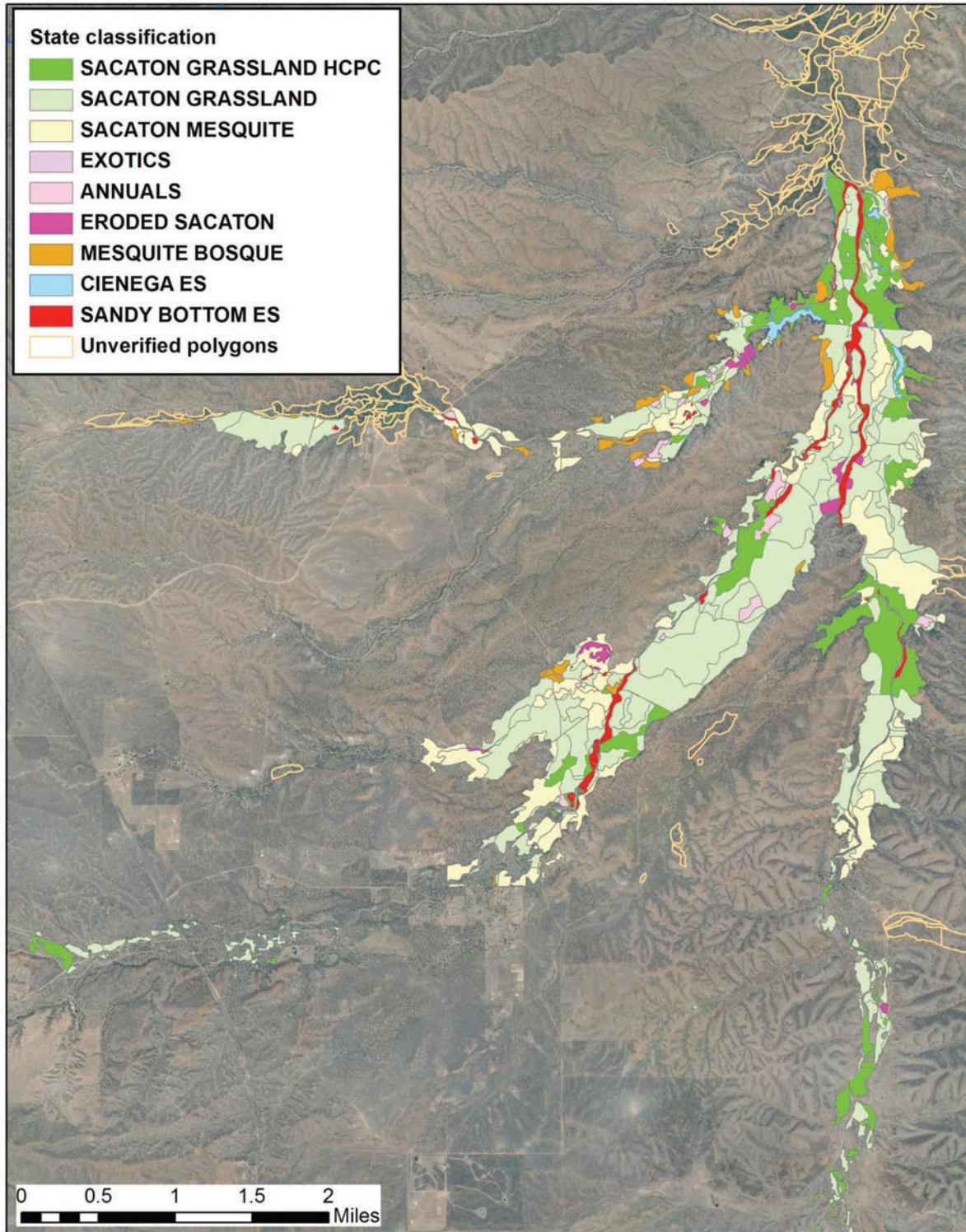


Figure 4—Ecological state map showing condition of sacaton stands (green through pink polygons) , plus extent of related riparian communities (orange, blue and red polygons with mesquite bosque, cienega, and cottonwood-willow forest respectively). Bright green represents highly productive, open sacaton stands in the condition closest to what is considered the “historic climax plant community “ (HCPC).

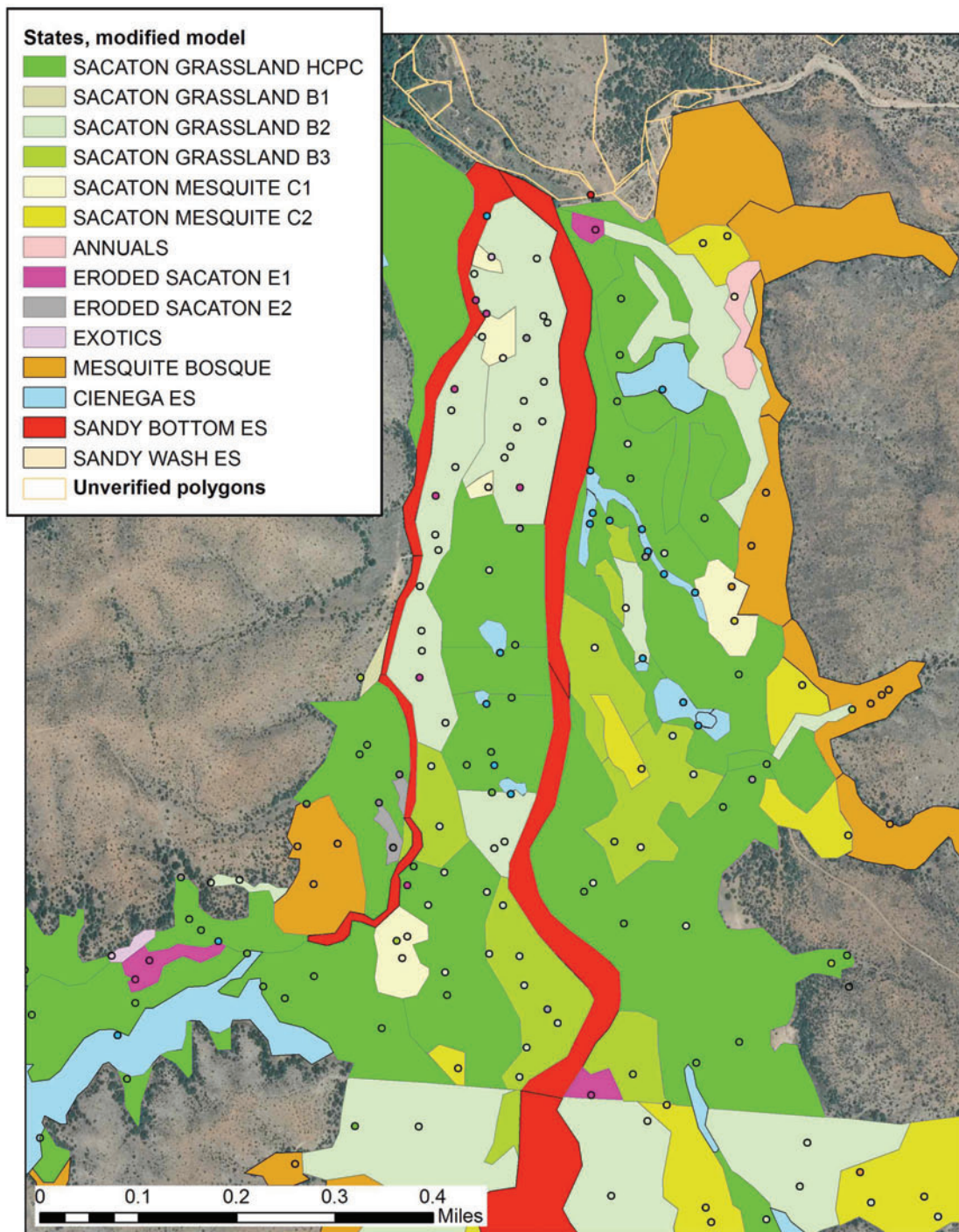


Figure 5B—Ecological state map using the modified model described in Figure 3. This classification shows finer distinctions in condition than are found among NRCS model states. Some model modifications call out distinctions that may be especially useful to managers, e.g. between actively eroding state E1 that may require restoration interventions versus stabilized erosion E2 that is healing on its own. Others reflect different dynamics observed in the field, e.g. sacaton-mesquite C1 with shrub form mesquite encroachment versus tree form mesquite in C2 on a more obvious trajectory towards mesquite bosque.

Figure 6—Example photographs of ecological conditions of Loamy Bottom ecological sites (rangeland and forestland) encountered in the upper Cienega watershed. Text conforms to Ecological Site descriptions; class letter assignments are those of authors.



Sacaton Grassland (Historic Climax Plant Community; state A): 25-80% sacaton ground over, 0-20% annuals, <20 feet depth to water table.



Sacaton Grassland (state B): 25-60% sacaton ground cover, 1-15% mesquite, <20 ft depth to water table.



Sacaton-Mesquite (state C): 5-40% sacaton ground cover, 5-20% mesquite, other shrubs and succulents, <20 ft depth to water table. This state known as Mesquite-Sacaton in Loamy Bottom S&T model.



Exotics (state D) – Exotic perennial grasses (e.g., Johnsongrass, yellow bluestem, and bermudagrass) with/without mesquite, <20 ft depth to water table. Johnsongrass (*Sorghum halepense*) dominates a patch of former sacaton grassland in the upper third of photo.



Eroded Sacaton (state E): 20-50% sacaton ground cover, no mesquite, exotic grasses present, gully erosion, >20 ft depth to water table.



Annuals-Sacaton Grassland (state F): Trace sacaton cover, no mesquite, 0-10% other shrubs and succulents, annuals present, >20 ft depth to water table.



Mesquite Bosque, native annuals (Historic Climax Plant Community; state H): no sacaton, 25-65% large mesquite, 0-5% other shrubs and succulents, 25-50 ft to water table.

existing conditions. Blending and refining models for rangeland and forestland sites and adding our observations of sub-states and linkages between them produced an alternate model (fig. 3) we believe more accurately represents what we mapped across Las Cienegas NCA. We offer management suggestions for Loamy Bottom Rangelands by state based on the revised S&T model, expertise of the authors, and supporting literature.

Sacaton Grasslands (states A, B1, B2, and B3) occupy about 2,156 acres here. While distributed along the length of the creek, these stands rarely occupy the entire length or width of a broad alluvial setting. Sacaton stands are not as homogeneous as anticipated; a mosaic of other conditions occurs around states A, B1 and B2, including Sacaton-Mesquite and Mesquite Bosque (see states below). Cienega and Sandy Bottom Ecological Sites also are found within and around this mosaic. The S&T model and additional research results suggest that Sacaton Grassland states A, B1, and B2 primarily require low-intensity management designed to maintain high grass cover and low shrub cover. Fire arguably has the greatest value for managing big sacaton and alkali sacaton ranges (Britton and Wright 1983; Wright and Bailey 1982) provided that frequency, extent, and seasonality of fire occurrence are considered for their overall health. Grazing management may affect how sacaton plants respond to other disturbances, with implications for the health of the grass stand. For maximum forage production, Cox and others (1989) recommend grazing big sacaton in the spring, not grazing in dry summers and dry years, and discontinuing fall grazing. The combination of fire and grazing produces very different effects compared to that of either activity alone (Vogl 1974).

Sacaton patches with moderate cover and appreciable woody plant encroachment are evident in three states. Sacaton Grassland (state

B3) occurs with low-medium cover of tall mesquite (>12 ft. tall) and vigorously growing sacaton with moderate cover. Sacaton-Mesquite conditions C1 and C2 are also evident (see below for C2). State C1 occurs with low-medium cover of shrubby mesquite (<12 ft. tall) with low-medium cover of less vigorous sacaton. In condition B3, sacaton appeared to co-exist with mesquite while in condition C1 the grass appeared to be in decline. Both states would benefit from management aimed at reducing woody cover with minimal soil disturbance. While mechanical grubbing is not recommended (Robinett personal communication, 2011), studies show that woody plant control with herbicides can significantly increase grass and forb production. Targeted applications to individual woody plants are best and might be useful in integrated brush management programs followed with fire.

Sacaton-Mesquite (state C2; known as Mesquite-Sacaton in Loamy Bottom S&T model) stands with tree-form mesquite (>12 ft. tall) appear to be in transition towards Mesquite Bosque (State H). This transitional pathway represents an important contribution of this study since it is not articulated in existing Ecological Site Descriptions (ESD) and their respective models for Loamy Bottoms. Our observations suggest that a site-by-site evaluation would need to be made on whether to control mesquite in these areas or allow them to transition to bosque, a desirable and rare plant community in its own right.

Eroded Sacaton Grassland is evident in two phases at this site: actively eroding (E1) and healing/healed (E2). In this watershed, State E1 appears as patches throughout the alluvial landscape, in areas of headcuts and gullies or sheet erosion. Management actions might focus on arresting and/or repairing erosion, for example, treating headcuts that threaten to dewater high quality sacaton grasslands. Treatments may include a combination of methods (e.g., Zuni bowls, one-rock dams, and media lunas; Zeedyk and Clothier 2009). Sheet

erosion areas vary from about one to several acre patches in size interspersed within grasslands (A-B2) and sacaton-mesquite (B3-C2) in the floodplains of Gardner Canyon and Empire Creek. Installation of controls to slow overland flow and capture sediment may be recommended management actions. Additional measures may include reseeding and/or re-vegetation with sacaton, or possibly with other native grass species. Select areas might be rested from grazing to enable re-establishment of plant cover on bare soils.

Eroded sacaton (state E2) occurs as healed or healing gullies or sheet erosion. We observed areas of former cutbanks with peeled back walls well-vegetated with sacaton or occasional wetland plants. In other places, we saw areas healing from sheet erosion where all but the original sparsely vegetated shallow cutbank was visible. Since state E2 is healing or healed of its own devices, we suggest no management actions.

Exotic perennials (state D) occur as small patches within states A and B. Johnsongrass (*Sorghum halepense*) is the most often observed exotic perennial grass, rarely occupying more than an acre at this site. Johnsongrass and bermudagrass (*Cynodon dactylon*) are most often associated here with cienega wetlands or along stream channels and gravel bars of Sandy Bottom ecological sites. At present, these grasses do not appear to threaten overall sacaton grassland condition since they appear to be more or less confined to wetland and near stream sites.

Annuals (state F) is largely restricted to abandoned agricultural fields. These fields are partially recolonized by sacaton, but more so by mesquite. Small-scale earth-moving might serve to promote recovery of sacaton and expansion of extant cienega. Presently, surface water from a cienega is precluded from reoccupying the southern portion of the fields by short levees (3-5 ft.) that could be breached. Monitoring the rate and direction of sacaton and woody plant encroachment onto these fields is a viable, low budget option for tracking the recovery of the fields with or without modifications to the levee or canal system.

Mesquite Bosque comprises state H. Most Mesquite Bosque found along Cienega Creek includes big sacaton plants as an understory component. Mesquite bosques support several trophic levels and great varieties of invertebrates, birds, bats and other animals because of the abundance and nutritional quality of food and high structural diversity. Considering wildlife values and Resource Management Plan directives for Las Cienegas NCA to protect and maintain mesquite bosque, the best management strategy may be to leave these woodlands alone regardless of how they came to be formed. Present day environmental conditions clearly favor mesquite bosque over sacaton grassland in some areas above, and most areas below, 4,300 ft. elevation.

Discussion

We produced an extensive GIS database for referencing our map of on-site sacaton grassland conditions and their distribution. Sacaton grassland is present on over 2,100 acres, supporting the contention that some of the finer examples in southeast Arizona occur in this drainage. This acreage includes pure sacaton flats with those experiencing the early-to mid-stages of mesquite encroachment. With little over half of the verified alluvial areas found to be in the most productive states (A-B2) of Sacaton Grassland, our observations speak to the timeliness of the BLMs request for information on the baseline condition of sacaton communities and its desire to guide management.

Sacaton communities are restricted to low gradient, alluvial environments yet, not entirely confined to what had been mapped as Loamy Bottom ecological site. We observed appreciable sacaton stands (states A-C1) in areas mapped as Loamy Swale and Sandy Bottom Wash Ecological Sites. Possibilities as to why this may be include: precision

of ecological site mapping in the mid-1990s was coarse enough that some sacaton grassland communities plot in Loamy Swale or Sandy Wash ecological sites; and, broad areas mapped as Loamy Swale and Sandy Wash are actually transitional between these ecological sites and Loamy Bottom.

Alkali sacaton (*S. airoides*) commonly occurs in states A-B3 of upper Cienega Creek watershed; it is even the dominant perennial grass in some areas. Cox (1984, 1985) reports that *S. wrightii* occurs on moderately alkaline and slightly calcareous soils, and is usually replaced by *S. airoides* in areas with very alkaline or saline soils. Since the S&T model for Loamy Bottom specifically addresses *S. wrightii* with *S. airoides* playing only a supporting role (Robinett 2005a), it is possible that some of the area previously mapped as Loamy Bottom is actually Saline Bottom (Womack 2005) or a combination of the two. Our field verifications did not include digging soil pits to validate Ecological Site classification at point locations, but we recognize this is a valuable effort when feasible.

The dynamics of change within sacaton grasslands, and the factors driving these changes, deserve additional validation and research. Field observations and review of the literature for this project suggested transitional pathways between sacaton grasslands and other riparian vegetation communities. These are addressed more fully elsewhere (Tiller and others 2012). Sacaton Grassland and Mesquite Bosque states transition between each other along successional trajectories. One or more linkages might be made between rangeland and forestland ecological sites, allowing them to flow fluidly between one another.

The vast majority of mesquite bosque stands of the upper Cienega Creek watershed include big sacaton plants as an understory component, suggesting that these woodland communities may be a product of recent environmental change (i.e., past 130 years; Bryan 1928). Sacaton growing in the understory of these woodlands is most likely a remnant of a former grassland condition and may persist in part where water tables remain high (Lacey and others 1975). Mesquite Bosque with trace or no sacaton understory is observed primarily at the mouth of upland swales that drain to sacaton grassland communities via side drainages. Many of these bosques also may be recent in occurrence since above 4,300 ft. elevation they are not visible in the earliest aerial photography captured in the mid-1930s.

As the field survey and data refinement phases of this project matured, modifications to improve efficiency in the future became apparent. Creating dropdown menus for field recordings using a suite of site descriptors would increase the consistency and reduce post-processing time by integrating field data directly into a GIS database. Future efforts with limited time for field visits might be best served by reducing field time spent classifying transitional areas and use aerial imagery to emphasize work in larger areas of specific interest.

Our case study represents a substantial contribution to the field because it provides (1) a more accurate map of what sacaton rangeland occurs and its ecological condition at this site; (2) a more inclusive model for understanding dynamics and management needs of sacaton, and related communities, across the region; and (3) refined methods for evaluating the distribution and condition of sacaton communities elsewhere. At present, the development of ESDs and S&T models is moving into a field validation phase (Dan Robinett, personal communication, 2011b). This case study has the potential to aid in the refinement of these models for use in other sacaton bottomland sites across the Sky Island region.

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Human Impacts

Long Distance Commutes by Lesser Long-Nosed Bats (*Leptonycteris yerbabuena*) to Visit Residential Hummingbird Feeders

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Abstract—Each spring, thousands of female lesser long-nosed bats (*Leptonycteris yerbabuena*) migrate from southern Mexico to northern Sonora and southern Arizona to have their young and take advantage of seasonably available forage resources, including nectar, pollen, and fruit of columnar cacti. Once the pups are volant, the population begins to disperse across the grasslands of southeastern Arizona, foraging on flowering paniculate agaves (*Agave palmeri*) and day-roosting in Madrean Sky Islands during their seasonal migration back to southern Mexico. Although the grasslands surrounding Arivaca, Arizona, have very low densities of naturally occurring agaves, nectar bats are documented visiting area hummingbird feeders to obtain sugar water. To better understand foraging patterns by these bats in an area with few natural food plants, we radio-tracked 28 *L. yerbabuena* during 2010 and 2011. We captured bats at area hummingbird feeders and tracked them to a previously unknown day-roost in the Santa Rita Mountains, approximately 40 km away. We discovered that bats nightly performed a long-distance commute from the Santa Rita Mountains to Arivaca, bypassing hummingbird feeders and naturally occurring agaves closer to their day-roost. It may be that the large colony size in the day-roost necessitates long-distance dispersal as a mechanism to reduce competition for limited food resources.

Introduction

The lesser long-nosed bat (*Leptonycteris yerbabuena*) was listed as endangered in the United States by the U.S. Fish and Wildlife Service (USFWS) in 1988 (Shull 1988). The northernmost population of this species is migratory, while a southern population near Jalisco, Mexico, appears to be present year-round (Ceballos and others 1997; Cole and Wilson 2006). Female *L. yerbabuena* are pregnant when they arrive in southern Arizona from central Mexico during April and May. These bats are highly gregarious and use a limited number of roosts with colonies numbering in tens of thousands of individuals. They give birth (typically in May) at large maternity roosts in Sonoran desertscrub habitat (Cockrum and Petryszyn 1991), feeding nightly on the nectar, pollen, and fruit of columnar cacti, including saguaro (*Carnegiea gigantea*) and organ pipe (*Stenocereus thurberi*) (Fleming and others 1993). During July and August, once the young are volant (able to fly), maternity colonies begin to disperse. Wilkinson and Fleming (1996) suggested two distinct migratory routes for the species, one along the west coast of Mexico and the other along the Sierra Madre Occidental with little genetic mixing between the groups.

However, more recent DNA analysis determined that there is general genetic mixing across southern Arizona and, for conservation efforts, the two groups should be considered one population (Ramirez 2011). The bats begin a gradual migratory path eastward, moving up in elevation and shifting to grassland communities where they feed on nectar and pollen of flowering paniculate agaves, primarily Palmer agaves ([Family Agavaceae, *Agave palmeri*]; USFWS 1997). Ober and others (2005) radio tracked *L. yerbabuena* in the Huachuca Mountains of southeastern Arizona and determined that these bats used home ranges with a greater density of flowering agaves (3.6 flowering agaves/ha) than the general landscape (1.8 flowering agaves/ha). In addition, nectar bats have discovered that hummingbird feeders offer energy resources during their migration across southern Arizona. Some researchers have speculated that nectar bats visit artificial food resources in greater numbers during years of reduced agave flowering, particularly after periods of below average winter rainfall (Krebs 2007, unpublished paper). Both *L. yerbabuena* and Mexican long-tongued bats (*Choeronycteris mexicana*) are documented using hummingbird feeders near Portal, Arizona, (Chiricahua Mountains) and in the Santa Rita Mountains since the 1970s (Cockrum and Petryszyn 1991). Recently, urban homes well within Tucson, Arizona, city limits have multiple feeders drained each evening between mid-August and late September (D. Buecher, personal observation 2011; Lowery and others 2009).

L. yerbabuena require caves and mine tunnels with specific temperature and relative humidity for day-roosts, as well as bridges and various abandoned man-made structures, for night roosts (Cockrum and Petryszyn 1991). Appropriate day roosts may be a limiting factor

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for the distribution of *L. yerbabuena* because they are documented flying 24 to 40 km nightly from a day roost to suitable foraging habitat (Horner and others 1998; Sahley and others 1993). Ober and others (2005) found that this species has large home ranges (505 ha), which allows them to access food resources across vast landscapes. Disturbance and/or loss of roost sites, combined with a gradual decrease in foraging habitat from increasing land development, are the most serious issues *L. yerbabuena* face in Arizona (USFWS 1997). Roosts in abandoned mine tunnels, caves, or old abandoned buildings in remote areas provide refuge for bats unless disturbance occurs. Increased presence of cross border violators (CBVs) along the border between the United States and Mexico, who use these same structures for shelter, contributes to disturbance to colonial bats (USFWS 2008). *L. yerbabuena* are also at risk when they frequent human structures for roosting purposes or to feed at hummingbird feeders because they are at risk of predation by domestic cats, being harmed by humans, or killed or injured through collisions with urban structures.

Visual surveys during our study indicated no large fields of agave plants (≥ 1.8 flowering agaves/ha) in the vicinity of Arivaca, Arizona, but *L. yerbabuena* had been documented using area hummingbird feeders in late summer. Therefore, we were interested in (1) which nectar bat species were using feeders; (2) how they used a landscape with few natural food resources, and (3) where they were day-roosting. Because bats are nocturnal it is often difficult to monitor nightly feeding behavior. However, radio telemetry helps elucidate the foraging behavior of *L. yerbabuena* (Ober and Steidl 2004; Ober and others 2005), and allows researchers to track bats across both temporal and spatial scales and identify flight corridors between day and night roosts (Amelon and others 2009).

Study Area

This study was conducted near the town of Arivaca, Pima County, in southeastern Arizona, USA (31°34'N, 111°19'W), an area surrounded by the Las Guijas Mountains, Cobre Ridge, Tumacacori Mountains, and Cerro Colorado Mountains. Arivaca is approximately 29 km west of the Santa Cruz River, 45 km west of the Santa Rita Mountains, and about 19 km north of the international border with Mexico. Although there is little natural foraging habitat for nectarivorous bats in the area, there are significant stands of flowering agaves during the summer months in the Santa Rita Mountains to the east. That range has at least four documented lesser long-nosed bat post-maternity roosts. Despite a scarcity of natural food plants near Arivaca, local residents have reported that their hummingbird feeders are often visited by bats in late summer. Arivaca is a small community (~ 900 residents according to the 2000 census), located at approximately 1100 m in elevation with homes concentrated on small lots in the historic town site and homes east of Arivaca on 0.5 ha lots to larger (≥ 4 ha) lots. The habitat surrounding Arivaca is semidesert grassland (Brown 1994) characterized by low rolling hills and ephemeral streams. Arivaca Creek, which contains dense cottonwood galleries, generally flows from east to west and is located less than 0.40 km south of Arivaca. The low undulating terrain of the study area made constant monitoring of telemetered bats sometimes difficult to achieve so radio-tracking stations were located on high points whenever possible, with views overlooking Arivaca and nearby canyons.

Methods

We captured up to 15 *L. yerbabuena* per year ($n_{2010} = 13$ and $n_{2012} = 15$) during post-maternity migration (five each in August, Septem-

ber, and October). We radio tracked the bats during three sessions, each lasting 2 weeks per month for a total of 6 weeks per year. Bats were captured at residential hummingbird feeders both in Arivaca and approximately 6.4 km east of Arivaca. Protocols outlined by the American Society of Mammalogists (Sikes and others 2011) were followed while handling all bats, and appropriate scientific collecting permits were maintained during this study. Because of the potential threat of White Nose Syndrome being spread between bats by humans, USFWS decontamination protocols outlined for bat researchers were followed during the capture and handling process (USFWS 2011). Radio transmitters (#LB-2N from Holohil Systems Ltd., Ontario) weighing 0.42g were attached to *L. yerbabuena* using colostomy adhesive. Prior to attachment of a transmitter, it was confirmed that the mass of the transmitter was less than 5% of the bat's total body mass (Aldridge and Brigham 1988).

During each session of radio tracking, three to five radio-tracking stations were maintained to monitor telemetered bats. Each station had a scanning radio receiver (R1000, Communications Specialists, Inc., Orange, California) and a three or five element Yagi antenna, a compass, and a long-range radio to maintain communication between stations. Each telemetry station was manned prior to sunset unless personnel were mobile and actively following a signal. To ensure that the radio receivers were functioning properly, test beacons were placed along undisclosed bearings and personnel took sightings on these prior to the evening's activities.

Each night, personnel constantly monitored all radio frequencies of bats telemetered during each month. If a signal was detected, the frequency and general bearing was communicated to all stations, and these stations attempted to monitor the frequency until the signal was lost. For each signal detected, the frequency, time of detection, bearing, and strength of the signal were recorded on data sheets. Personnel were able to continue scanning all frequencies while monitoring a particular frequency. If a new frequency was detected, the monitor would obtain a bearing for the newly detected frequency and coordinate with other stations. In order to better define foraging areas, both stationary radio tracking stations and mobile stations were used to monitor *L. yerbabuena* behaviors and habitat use. The program LOAS 4.0.3.8 (Ecological Software Solutions, LLC) was used to determine intersections from telemetry station bearings. Because of the low rolling terrain of the area, three simultaneous points were not always achieved on bat detections so 'Best Biangulation' was used to determine bat locations. We conducted statistical analysis on the radio tracking data using the software package JMP4.0 (SAS Institute Inc. 1996).

Results

During the 2-year study, we tracked 28 *L. yerbabuena*, including 17 adult females, 7 subadult females, 1 adult male, and 3 subadult males. The first session of radio tracking each year was conducted in mid-August, when nectar bats are documented in southeastern Arizona grasslands; the last session was conducted in early October (USFWS 2007; Sidner 2010). During each study month in 2010 and 2011, three to five *L. yerbabuena* were each affixed with a radio transmitter that was approximately 3% of their body mass and released. Upon release of a bat, radio telemetry stations immediately began monitoring its movements. During 2010-2011, we captured 134 bats of seven different species while mist netting for *L. yerbabuena* on the patios of homes and at two flowering agaves (table 1). All species captured were expected to occur in semidesert grasslands of southeastern Arizona (Hoffmeister 1986). The diversity of bats was higher than expected at hummingbird feeders because two residences used for

Table 1—Mist netting results from the 2010-2011 radio telemetry survey near Arivaca, Arizona.

Scientific name	Common name	Number Caught
<i>Antrozous pallidus</i> ^a	Pallid bat	1
<i>Eptesicus fuscus</i> ^a	Big brown bat	4
<i>Choeronycteris mexicana</i> ^b	Mexican long-tongued bat	86
<i>Leptonycteris yerbabuenae</i> ^b	Lesser long-nosed bat	33
<i>Myotis auricolus</i> ^a	Southwestern myotis	2
<i>Myotis velifer</i> ^a	Cave myotis	7
<i>Tadarida brasiliensis</i> ^c	Brazilian free-tailed bat	2

^aVespertilionidae
^bPhyllostomidae
^cMolossidae

netting had large porches that offered night roosting opportunities for many bat species. Despite the lack of food plants for nectarivorous bats within the study area, we captured a surprising number of both *L. yerbabuenae* (n = 33) and *C. mexicana* (n = 86) over the course of the study. In 2010, despite radio tracking for 14 nights per month, we were unable to continuously track bats over multiple consecutive nights. During August, we tracked five *L. yerbabuenae* for only one night each; in September we tracked five bats for one to three nights each; and in October we tracked three bats for one to two nights each. Because the 2010 radio tracking had such limited results, no statistical analyses were conducted. However, signals from telemetered bats were detected in the vicinity of the Santa Rita Mountains to the east, so we suspected the bats might be using a day-roost in that mountain range.

The radio tracking sessions in 2011 were more successful and we had sufficient numbers of bearing intersections for statistical analysis. In August 2011, we captured five *L. yerbabuenae* at a residence approximately 6.4 km east of Arivaca. Two of the bats had modest to abundant plant pollen on their heads and face, indicating that they were successful in finding pollen-bearing flowers, most likely agaves, before visiting the hummingbird feeders. We tracked these animals for 3 to 10 nights ($\chi = 6$, SE = 1.18) before the signals were lost. August bearings on telemetered bats were used to calculate location intercepts using LOAS (2011) (fig. 1). One bat disappeared from the area after one night so the behaviors of the remaining four were analyzed statistically. These bats behaved as a group and the latitudes and longitudes of their bearing intersections were similar (ANOVA_{latitude} $F_{3,79} = 1.38$, $P = 0.26$, ANOVA_{longitude} $F_{3,79} = 0.71$, $P = 0.55$). As a group, these animals concentrated their foraging efforts east of Arivaca. In August 2011, we were able to track telemetered bats to an abandoned mine in the Santa Rita Mountains where we found five of our radio transmitters on the floor (four from 2011 and one from 2010). A subsequent exit count documented approximately 7,000 *L. yerbabuenae* emerging from the mine at sunset. After the bats were gone, a trip into the site found five additional transmitters (one from 2011 and four from 2010).

In September, we captured five *L. yerbabuenae* at a residence in Arivaca, where the homes are located closer together. We tracked these animals for two to nine nights ($\chi = 4.2$, SE = 1.72) until the signals were lost. September bearings on telemetered bats were used to calculate location intercepts using LOAS (2011) (fig. 2). The September bats flew more directly to Arivaca, the area where they were captured, and foraged around homes closer to town. Statistical analysis of the five bats shows that they behaved as a distinct group within latitude (ANOVA_{latitude} $F_{4,146} = 0.88$, $P = 0.48$), but not strongly within longitude (ANOVA_{longitude} $F_{4,146} = 5.88$, $P < 0.001$). Statistical

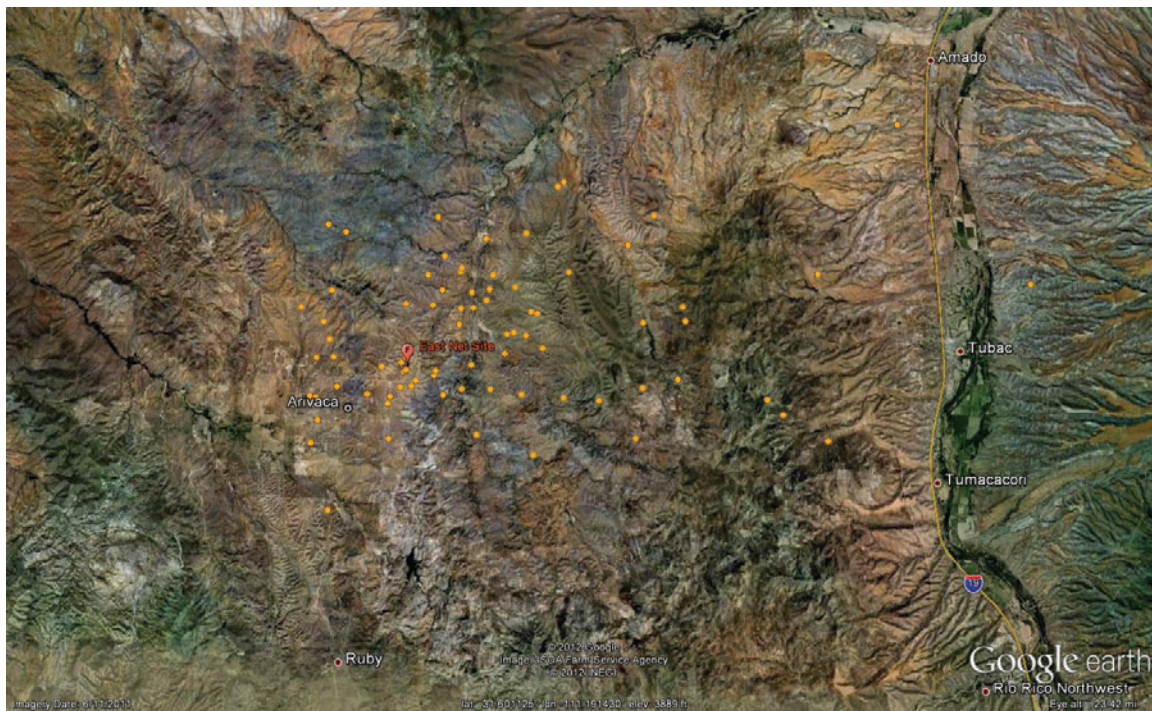


Figure 1—Gold circles indicate intersection locations from LOAS for five telemetered bats during August, 2011. These points indicate where *L. yerbabuenae* were flying in relation the capture site east of Arivaca

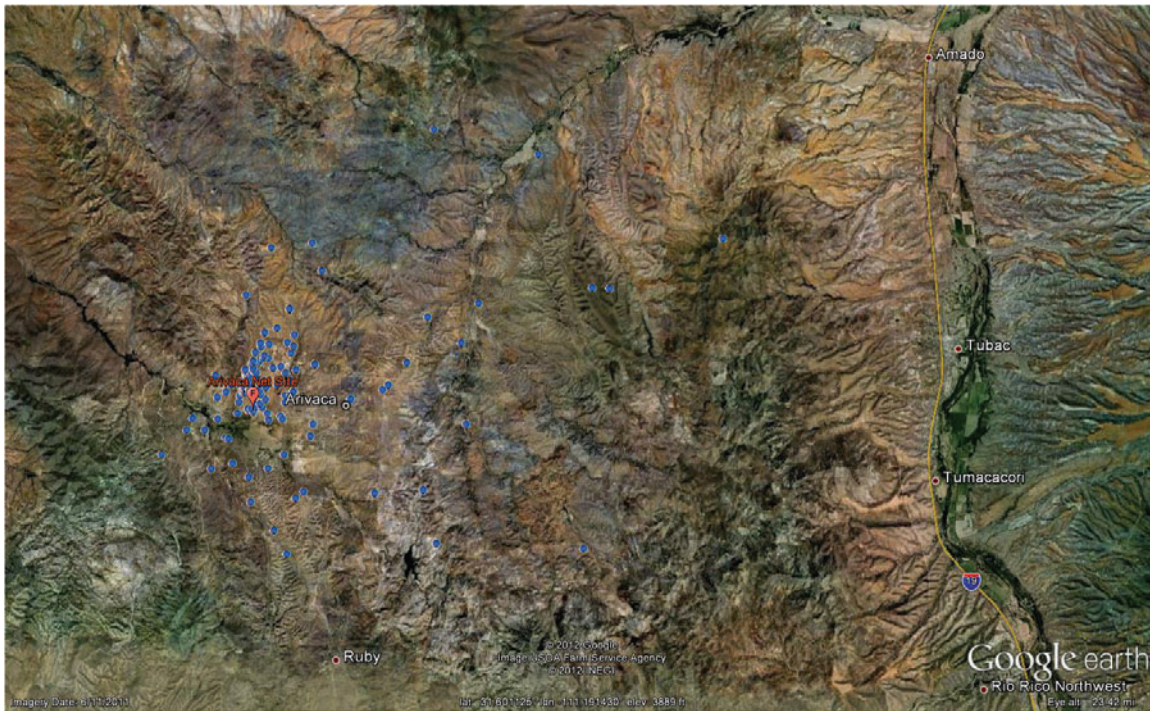


Figure 2—Blue circles indicate intersection locations from LOAS for five telemetered bats during September, 2011. These points indicate where *L. yerbabuena* were flying in relation to the capture site in Arivaca.

analysis of behavior differences between bats telemetered in August (6 km east of Arivaca) to bats telemetered during September (in Arivaca) showed a significant difference between the latitude where these bats foraged ($t_{228} = -12.49$, $P < 0.001$). Some of the bats captured 6.4 km east of Arivaca did fly as far as Arivaca; however, they consistently used more areas east of town than those bats captured in Arivaca itself. Bats originally captured at feeders in Arivaca flew more directly to that area before settling down to forage most of the night. Differences in longitude are not as pronounced, but still significant ($t_{228} = -2.73$, $P = 0.01$), with bats captured east of Arivaca flying more to the north than bats that were captured in Arivaca.

In October, we captured eight *L. yerbabuena*: five at the same Arivaca residence as in September and three at the same residence as in August east of Arivaca. The plan for this last month was to radio track five *L. yerbabuena* captured at two different sites. It was hoped that this could elucidate if bats acted as distinct groups and used different foraging patterns, depending on their capture site. We tracked the telemetered bats for four to eight nights ($\chi = 5.8$, $SE = 0.63$) until signals were lost. October bearings on telemetered bats were used to calculate location intercepts using LOAS (2011) (fig. 3). The October bats did not forage with a distinct configuration, but appeared to combine both the behaviors of August bats and September bats. When these five bats are analyzed statistically they behaved significantly differently across latitude (ANOVA_{latitude} $F_{4,76} = 0.23$, $P < 0.001$), distributed from east to west between the two capture sites. However, longitudinally they behaved as a group (ANOVA_{longitude} $F_{4,76} = 1.24$, $P = 0.30$), staying within a limited north to south range.

Once the day roost was found, we were able to estimate average flight speed for telemetered bats by using a telemetry station along I-19 to document exit times from the roost, while one or two stations in the Arivaca Valley detected the bats once they crossed the Tumacacori Mountains. Eleven bats were documented traversing this distance for

an estimated average speed of 28.3 kph. Sahley and others (1993) found similar speeds (27.2 kph) by *L. yerbabuena* commuting from a day-roost in Sonora, Mexico, to forage on flowering columnar cacti. *L. yerbabuena* visiting hummingbird feeders in the Tucson basin (table 2) travelled to foraging areas a bit faster (32.8 kph) although these animals were commuting from multiple day-roosts (Lowery and others 2009). All nectar bat flight speeds are significantly faster than documented for many regional insectivorous bat species (Hayward and Davis 1964). Sahley and others (1993) suggested that the large body size and high wing loading of *L. yerbabuena* may be an adaptation for long-distance commutes to food resources across naturally heterogeneous landscapes.

Discussion

We were unable to consistently track telemetered bats in 2010 because of issues related to losing the radio signals almost immediately after bats were telemetered. Unfortunately, when a transmitter is not detected once affixed, there are three possible reasons: (1) the bat continued its migration to another foraging area in southeastern Arizona; (2) the bat migrated towards its winter site in Mexico; or (3) the transmitter was groomed off at a day- or night-roost. In 2010, we assumed that these bats were continuing their migration from west to east across southeastern Arizona to Madrean Sky Islands where there were good stands of flowering agaves. The fact that nectar bats were captured in semidesert grassland that lacked stands of agaves was attributed to their learned knowledge that hummingbird feeders offered sugar-water to ‘power’ them across inhospitable landscapes (Cockrum and Petryszyn 1991; Lowery and others 2009). However, in 2011 we were more successful in continually monitoring telemetered bats and we were able to document bats commuting between their day-roost in the Santa Rita Mountains to hummingbird feeders

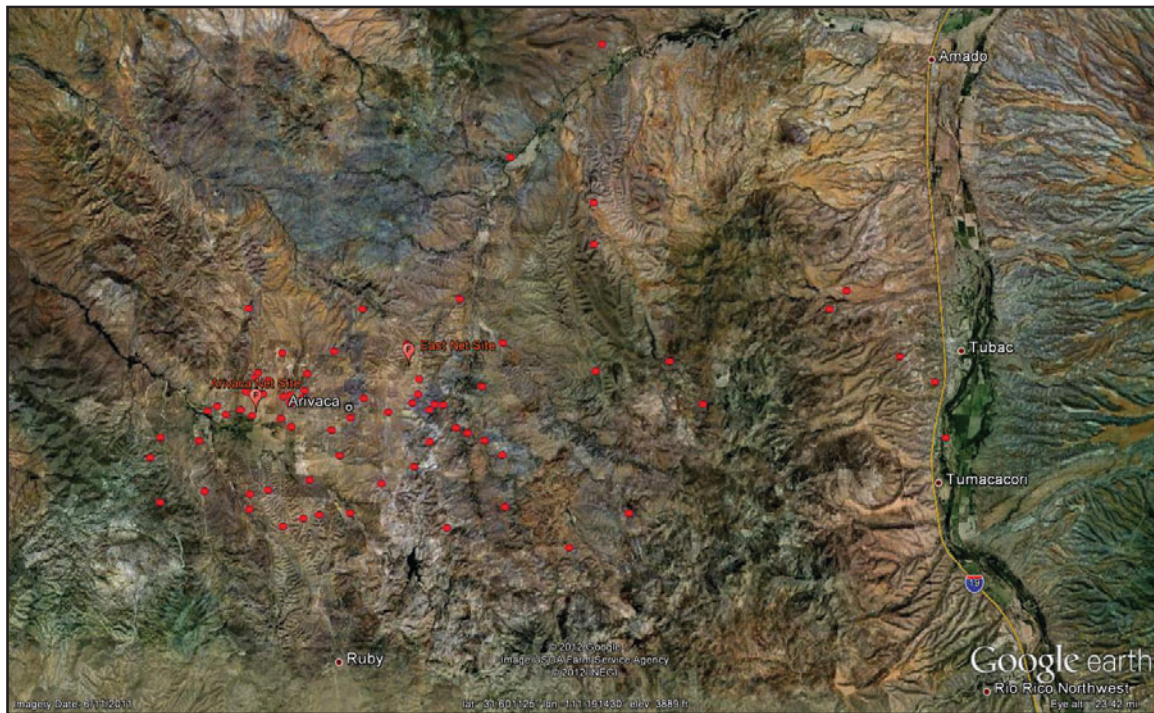


Figure 3—Red circles indicate intersection locations from LOAS for five telemetered bats during October, 2011. These points indicate where *L. yerbabuenae* were flying in relation to the two capture sites, one in Arivaca and one east of Arivaca.

Table 2—Flight distances and speeds recorded for lesser long-nosed bats reported by various researchers.

Source	Year	Location	Distance	Avg. Speed	Food Resources
Buecher/Sidner	2011	Pima Co., AZ	35.4 km	28.3 kph	sugar water
Horner et al.	1998	Sonora, Mexico	32.5 km	15.5 kmh	columnar cacti
Lowery et al.	2009	Pima Co., AZ	28.8 km	32.8 kph	sugar water
Ober et al.	2004	Cochise Co., AZ	19.2 km	unknown	paniculate agaves
Sahley et al.	1998	Sonora, Mexico	27.2 km	27.2 kph	columnar cacti
Sidner	1995	Cochise Co., AZ	27.4 km	unknown	paniculate agaves

in Arivaca. The discovery of both 2010 and 2011 radio transmitters groomed off in the roost documents bats from both years using the mine for day-roosting. All bats captured in Arivaca during 2011 were found day-roosting a majority of the time in the Santa Rita roost, approximately 32-38 km east of the capture sites. What is interesting about this behavior is that these *L. yerbabuenae* appear to nightly bypass naturally occurring agaves in the Santa Rita Mountains and closer hummingbird feeders along the more urbanized I-19 corridor. Hummingbird feeders in Tubac, Green Valley, and even Patagonia and Sonoita were closer to the day-roost than the Arivaca feeders (table 3). This seemingly unusual behavior may be an effort by individuals in a large colony to partition available food resources. The Santa Rita Mountains have at least four known lesser long-nosed day-roosts with an approximate regional population of 16,000 bats. Because the newly discovered Santa Rita roost has approximately 7,000 bats, these animals might be required to disperse across a broad landscape in order to find sufficient food resources. The telemetered animals were all captured in or near Arivaca, which may bias the results towards those individuals that have already chosen this area to feed, whereas other *L. yerbabuenae* in the day-roost may forage at closer feeders.

Despite a lack of flowering agaves in the Arivaca area, nectar bats are actually present in good numbers, presumably because they have ‘learned’ to utilize sugar water resources at urban homes to maintain their energetic needs during migration across southern Arizona. Overall, these animals were highly loyal to this artificial food source (sugar water) and some bats returned many nights to the area after capture.

When the telemetered bats are evaluated as a group, the bats captured 6.4 km east of Arivaca behaved as a unit and did not forage differently when measured spatially. Bats captured in Arivaca also behaved as a unit and travelled farther towards Arivaca to feed. Howell (1979) hypothesized that *L. yerbabuenae* foraged in groups as a benefit for locating food resources in a heterogeneous landscape. Our results support this hypothesis by showing that bats captured at specific sites behaved strongly as a group on subsequent nights. When the 2 months (August and September) are compared there is a significant difference in the foraging areas the bats used. However, during October, when the sampling for bats was conducted from two residences 6.4 km apart, the combined group foraged across all latitudes and longitudes reflected by the August and September bats. Since these

Table 3—Distances from the Santa Rita day-roost to area hummingbird feeders. Bold italic entries indicate feeders definitely used by the telemetered bats during 2010-2011 radio tracking. Note that five urban areas where feeders are closer to the day-roost than Arivaca, Arizona.

Feeder locations	Santa Rita roost
	<i>miles (km)</i>
Tubac	7 (11.2)
Patagonia	13 (20.8)
Continental	14 (22.4)
Sonoita	16 (25.6)
Green Valley	18 (28.8)
East Arivaca	20 (32)
Sahuarita	22 (35.2)
Arivaca	24 (38.2)
West Arivaca	27 (44.8)

bats behave so cohesively on the landscape, it would be interesting to understand how they initially segregate themselves into foraging groups. Three possibilities might be (1) kin groups; (2) members of summer maternity colony cohorts; or (3) winter colony cohorts.

The results of our radio tracking study provide important information on activity patterns and foraging behaviors of *L. yerbabuena* on artificial food resources near Arivaca, Arizona. While this area was not previously documented for having regular visitation at urban hummingbird feeders by nectar bats, our high capture rates show that feeders are used by both *L. yerbabuena* and *C. mexicana*. However, one question, still to be determined, is how much do these animals benefit physiologically from this highly artificial food? The flowers of columnar cacti and paniculate agave offer nectar, but also large amounts of pollen, which have amino acids that the bats convert to proteins (Howell 1974). Horner and others (1998) estimated that the energy budget of *L. yerbabuena* was ~40 kJ/day and it took 80-100 visits to columnar cacti flowers to obtain this energy. It is currently unknown how many visits would be needed to artificial food resources to obtain an equal amount of energy. Another concern is how hummingbird feeders impact the natural foraging behaviors and migration patterns of nectar bats. Without the availability of urban hummingbird feeders, there is very little reason for nectar bats to be foraging in the grasslands surrounding Arivaca. There has been work to quantify how many agave plants are needed to maintain *L. yerbabuena* populations (Ober and others 2005). Although the grasslands surrounding Arivaca appear to have few agaves, fortunately there are naturally occurring stands of agaves in many of the Sky Islands to the east of Arivaca. This allows nectar bat populations to persist in the region and offers resources required during energetically costly migration for *L. yerbabuena* migrating to winter roosts in Mexico.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Effects of Roads on Wildlife in Arizona: How Far Have We Traveled?

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Abstract—Roads are conspicuous and pervasive features of landscapes and represent one of the most significant anthropogenic impacts on natural areas and wildlife. The Madrean Archipelago is defined by natural levels of fragmentation due to geography; however, human population growth and transportation needs threaten to exacerbate levels of isolation in the region. Scientists, as well as transportation and resource management agencies, have increased their concern about road impacts on wildlife. To identify needs of future research and managements, we reviewed 29 road-ecology-related, peer-reviewed publications and governmental research in Arizona and compiled geography, focal species, and topic. A taxonomic bias toward large mammals (72%) is evident. Study areas are concentrated along highways and state routes (76%). Despite a prevalence of studies on wildlife road crossing, most research focuses on distribution and movements, whereas impacts at the population and community level are rarely described.

Introduction

Roads are conspicuous and pervasive features of landscapes and represent one of the most significant anthropogenic impacts on natural areas and wildlife (Forman and Alexander 1998). Over 20% of the land in the United States is affected by roads and traffic (Forman 2000). Road construction causes destruction of habitat and habitat loss directly and facilitates deforestation and landscape fragmentation (Coffin 2007). Roads and traffic can cause mortality, impede and alter movements of animals, influence population density (Fuentes-Montemayor and others 2009; Roedenbeck and Voser 2008; Rytwinski and Fahrig 2007; Trombulak and Frissell 2000), and change community structure (Bissonette and Rosa 2009; Goosem 2000).

The Madrean Archipelago is defined by natural levels of fragmentation due to geography; however, increase of human population and transportation needs threaten to exacerbate levels of isolation in the region (ADOT 2006). The human population has increased 24.6% in Arizona, from 5.1 million in 2000 to 6.4 million in 2010 (U.S. Census Bureau 2012). The road system in Arizona has expanded dramatically from two rough roads in the 1800s to around 92,800 km of roads nowadays (ADOT 2012). With the increase in wildlife-vehicle collisions in Arizona, transportation and resource management agencies have elevated their concern about road impacts on wildlife and recognize the need to develop effective mitigation (Ruediger and others 2005). In this paper, we search road-ecology-related, peer-reviewed publications and governmental research reports and determine geography as

well as species and study focus to assess diversity and identify gaps in publications and research projects related to road impacts on wildlife in Arizona.

Materials and Methods

Literature Search

We used the *Web of Science* literature search tool that includes publications from 1945 to April 22, 2012 to search publications related to roads and wildlife in Arizona. We selected the “Topic” search option and used search terms “road and Arizona” and “highway and Arizona.” We browsed titles and abstracts in the search results and included publications related to wildlife in our analysis. For governmental research reports, we focused on research projects conducted by Arizona Department of Transportation (ADOT) and Arizona Game and Fish Department (AZGFD). To search project reports about road impacts on wildlife, we browsed ADOT research projects (SPR reports) from 1968 to 2012 in the website (http://www.azdot.gov/TPD/ATRC/Publications/project_reports/index.asp), AZGFD technical reports from 1990 to 1999 (http://www.azgfd.gov/w_c/Technical_Reports.shtml), and AZGFD wildlife and conservation research webpage (http://www.azgfd.gov/w_c/research.shtml). We also used the following internet resources to search other research reports not under ADOT and AGFD, including Wildlife and Roads Search Engine (<http://www.wildlifeandroads.org/search/>), Transportation Research Board (<http://www.trb.org/Main/Home.aspx>), TRID database (<http://trid.trb.org/>), and Google Scholar (<http://scholar.google.com/>). We realize that some peer-reviewed articles and governmental reports might be missed because of lack of congruence between keywords that we used and publications and the availability of governmental works to public.

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Variables

We recorded year of publication, focal species, research location, and the main topic for each peer-reviewed literature and governmental research project. To analyze the taxonomy of the focal species, we recorded the number of publications for each vertebrate animal class. For publications with mammals as focal species, we recorded the number of publications for each Order. We categorized the focal mammalian species as small mammals if body mass was less than 5 kg (Merritt 2010). We used the midpoint of adult body masses; female body mass was used in sexually dimorphic species (Hoffmeister 1986).

Results and Discussions

Do We Have Progress?

We found a total of 30 studies related to road impacts on wildlife, with 10 peer-reviewed articles, and 20 governmental research projects conducted by ADOT, AZGFD and U.S. Geological Survey. We excluded projects that are in-progress or unpublished because information on research is not consistently accessible. With rapid development of the subdiscipline of road ecology since 2000, the number of publications has increased considerably (1900%) in the past 16 years, from 1 publication by Rosen (1994) in 1994-2000 to 19 publications in 2006-2011 (fig. 1). The increased interest from governmental agencies in the integration of scientific research with decision making on transportation planning had positive impacts on the accumulation of knowledge of road-wildlife interactions and likely enhanced the publication of peer-review literature.

What Species Are Underrepresented? Does the Size Have Influence?

Among 30 studies, the most common taxon of study is the mammals (77%; fig. 2) with few studies on reptiles (10%), birds (3%), or general survey on multiple taxonomic groups (10%). No case study examines amphibians; however, road kill is a major source of

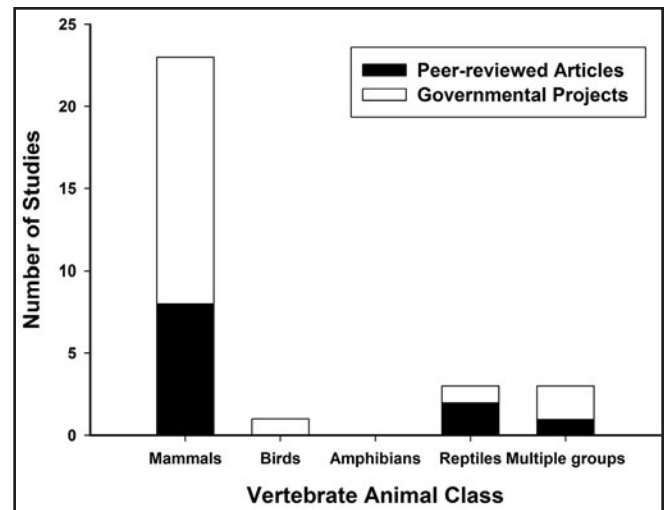


Figure 2—Number of studies related to road impacts on wildlife in Arizona by vertebrate class from 1994 to 2011.

amphibian mortality and may contribute to global decline of amphibians (Glista and others 2008). Our effort to understand road effects on mammals in Arizona does not extend equally to all Orders. Order Artiodactyla (ungulates) is the most frequently studied group and elk (*Cervus elaphus*) and desert bighorn sheep (*Ovis canadensis*) are the two most common studied species. When we look at the number of studies against the proportion of total species for each order of mammals in Arizona, a taxonomic bias toward ungulates is evident (fig. 3). Ungulates represent 4% of total mammalian species in Arizona, but were the subject of 96% of the studies. Compared to large and medium mammals, small mammals, which constitute 85% of the state's mammalian species, received a disproportionately small amount of attention in these studies (fig. 4). Of course, vehicle collisions or evasive driving maneuvers focused on small mammals

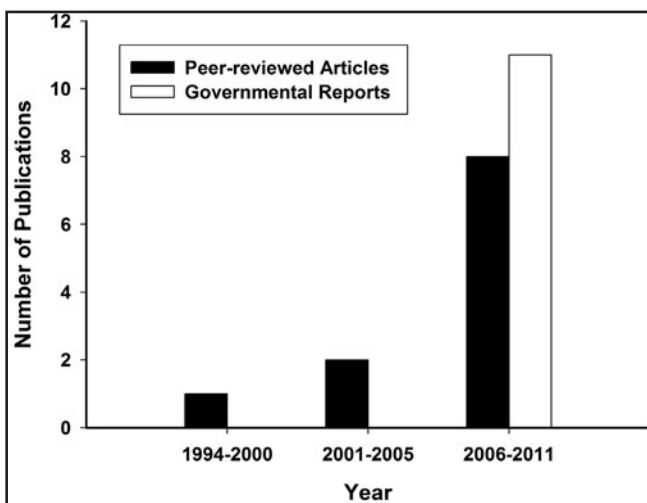


Figure 1—Number of publications related to road impacts on wildlife in Arizona by year from 1994 to 2011.

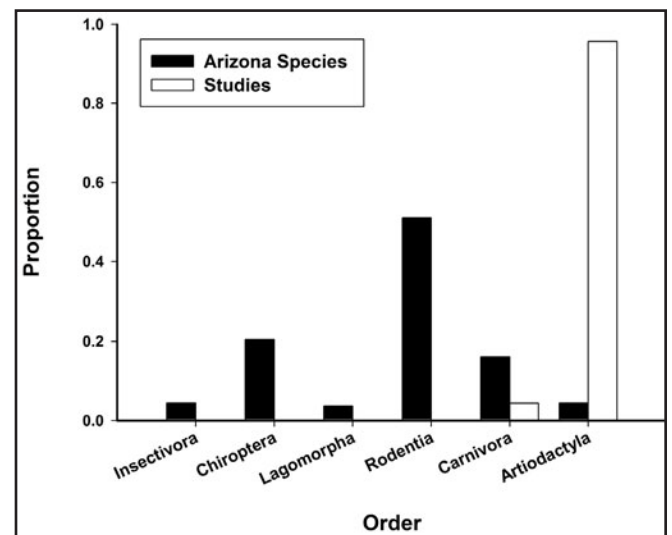


Figure 3—Relative proportions of Arizona mammalian species by order compared with representation of those orders in studies related to road impacts on wildlife from 1994 to 2011.

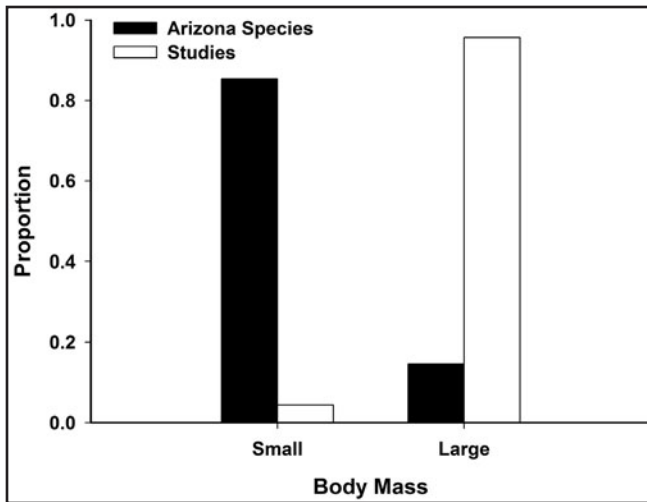


Figure 4—Relative proportions of Arizona mammalian species by size class compared with representation of those size classes in studies related to road impacts on wildlife from 1994 to 2011.

do not generally cause property damage or injury to humans, factors that, in part, drive this disproportionate distribution of publications.

Where Are We On the Road?

Current road and wildlife related research in Arizona mainly focuses on the barrier effect of roads on animal movements and efforts to improve motorists' safety. Road type is biased in research location with most efforts focused on highways and state routes (77%). Research topics are aimed at improved road permeability, reduced wildlife-vehicle collisions, and evaluating effectiveness of wildlife passages. Arizona has taken a leadership role in mitigation measures to minimize barrier effects of roads and to restore connectivity by designing and installing wildlife underpasses, overpasses, wildlife-proof fencing, and alert systems along highways and state routes (Reuer 2007). Besides wildlife passages, governmental agencies and scientists also continue to investigate the efficacy of currently installed structures (for example, culverts) as road crossing structures (Mikele and Michael 2007). With this amount of effort, the frequency of wildlife-vehicle collisions has declined and highway permeability for elk has been improved (Dodd and others 2007).

Where Is the Gap?

Our analyses suggest that a gap in knowledge of road impacts on wildlife exists in Arizona. Most importantly, we know very little about the impacts of roads on wildlife in Arizona and in unique biomes such as the Sonoran Desert. If we acknowledge a general dearth of literature on road impacts, we can examine if there are important areas where additional studies are required and prioritize our needs. We have already addressed the paucity of studies on groups beyond large mammals. Large mammals are important focal species because these animals are highly vulnerable to roads in part because they are more likely to encounter roads due to extended movement and ranges, and populations are more susceptible to road mortality because of low reproductive rates and low natural density (Fahrig and Rytwinski 2009). However, negative effects of roads occur across a wide range

of vertebrates (Laurance and others 2009; Wisdom and others 2000), and abundant evidence suggests that response to roads and traffic likely vary considerably across species (Goosem 2001; Laurance and others 2004; Taylor and Goldingay 2010). For example, roads restrict movements of forest-dependent species of birds but not frugivorous and edge and gap species (Laurance and others 2004). Whereas large mammals tend to avoid roads, response of small mammals to roads is more complicated (Fahrig and Rytwinski 2009). Despite the extensive size of forest road networks (Coghlan and Sown 1998), forest roads are relatively ignored. Several studies have demonstrated that even narrow roads less than 10 m wide can have barrier effects (Forman and Alexander 1998; Swihart and Slade 1984; Wilson and others 2007). Environmental changes associated with edges created by forest roads may impact species composition within the forest ecosystem, especially for species, such as tree squirrels, that are sensitive to forest fragmentation (Koprowski 2005; Murcia 1995).

Besides a taxonomic and geographic bias toward large mammals and highways in current studies, we need to develop research questions at different levels and scales. Despite several calls for needs and increased attention to research at population and community levels (Fahrig and Rytwinski 2009; van der Ree and others 2011; Underhill and Anhold (2000), these kinds of research are scarce in Arizona. We have gained important knowledge of barrier effects on individual animal movements, but we know less about effects of roads on populations. Does the magnitude of population fragmentation caused by barrier effects of roads affect population persistence? How do roads affect social structure and reproductive success within populations? Most road ecology studies focus on single species, and few assess community level impacts or address species interactions near roads. The danger of this is that we might miss important pieces of a complex system. For example, abundance of rodents often increased at areas near roads, potentially due to the negative effects of roads on predator populations, which cannot be known if we only investigate a single taxon or closely related species (Bissonette and Rosa 2009; Rytwinski and Fahrig 2007). We tend to have focused on patterns but do not fully understand the causes and mechanisms. For example, we know that roads have barrier effects on several species such as desert bighorn sheep, pronghorn (*Antilocapra americana*), and species of snakes, but do not know why (Dodd and others 2010; Jones and others 2011; McKinney and Smith 2007). Do animals avoid roads because of a gap in cover, or environmental changes along road edges, or traffic disturbance? Studies that address the relative importance of different mechanisms of the effects of roads on wildlife are needed (Roedenbeck and others 2007).

Our Roads Ahead

The Madrean Archipelago is a region that exhibits high levels of diversity and is fortunately less disturbed compared to many other places in the United States. Although the transportation system has expanded in recent decades, road density remains relatively low (World Bank 2008), so that ample opportunities exist to minimize road impacts in this region. One substantial challenge in management of road network systems is that no attempt has been made to synthesize piecemeal information from individual studies into a substantial, comprehensive picture about how road networks function in broader scale within the Southwest (Gucinski and others 2001). The need for increased cooperation between governmental departments and agencies is clear. Comprehensive planning that would minimize road effects requires collaboration among academia, public interest groups, and local, state, and federal agencies. We encourage enhanced multi-disciplinary, inter-agency supported events such as the International Conference

on Ecology and Transportation (ICOET) and Infra Eco Network Europe Meetings (IENE) as well as projects that address large scale landscape management. We believe that large scale efforts such as The Wildlands Projects (McDonnell 2002) and Arizona's Wildlife Linkages Assessment (ADOT 2006) as well as increased interest by university scientists and the history of a firm commitment to collaborative research among agencies provide the scaffolding for such a region-wide approach in Arizona. With continued expansion of the human population predicted for Arizona on the order of 7.4 million people by 2020 (ADOT 2006), as well as long term projections of significant redistribution and fragmentation due to climate change (Opdam and Wascher 2004; Weiss and Overpeck 2005), construction of a comprehensive and collaborative long-term plan is necessary.

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Tools for Research

Wildlife Survey and Monitoring in the Sky Island Region with an Emphasis on Neotropical Felids

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Abstract—The Sky Island region of southwestern United States and northwestern Mexico consists of isolated mountain ranges separated by deserts and grasslands. It mixes elements from five major ecosystems: the Rocky Mountains, Sierra Madre Occidental, the Sonoran and Chihuahuan deserts and the Neotropics. Here some Neotropical species reach their northern ranges, such as jaguars (*Panthera onca*) and ocelots (*Leopardus pardalis*). Sky Island Alliance seeks to build cooperative relationships with landowners in Sonora and public land managers in Arizona to facilitate scientific research, encourage large predator conservation, and establish corridors connecting patches of continuous habitat throughout the region. We have conducted wildlife surveys with remote cameras in northern Sonora since 2007 and in Arizona since 2009. Our photographic records cover 24 species of wild mammals, including jaguar (*Panthera onca*), ocelot (*Leopardus pardalis*), puma (*Puma concolor*) and bobcat (*Lynx rufus*). In 2009 we documented Arizona's first live ocelot, and recently we documented two individual jaguars 30 miles south of the border in Sonora. The project's results have increased our knowledge of borderland wildlife, especially the Sonoran ocelot, and supported the certification of a 10,000-acre private ranch as a wildlife preserve in northern Sonora.

Introduction

In 2005, Sky Island Alliance initiated a study on cross-border permeability in northern Sonora, Mexico, to establish corridors connecting habitat throughout the region, and create a network of conservation ranches in northern Sonora (Avila 2009).

Neotropical felids have been recorded in southern Arizona and northern Sonora (Brown and Lopez-Gonzalez 2001; Grigione and others 2007; McCain and Childs 2008; Rosas-Rosas and others 2010). Brown and Lopez-Gonzalez (2001) provide a comprehensive account of these Neotropical felids throughout the Sky Island region up until the end of the 1900s. Both Neotropical species are protected in the United States and Mexico. Currently the U.S. Fish and Wildlife Service (USFWS) leads recovery efforts for both species. Because of their low density and solitary nature, little is known about their population size, range, or habitat requirements in the United States (Grigione and others 2007).

At least six male jaguars have been recorded north of the border since 1996. There were two different sightings in 1996: one in the Baboquivari Mountains (Childs 1998), and another in the Peloncillo Mountains (Glenn 1996). McCain and Childs (2008) monitored at least two jaguars on the Atascosa, Tumacacori, and Baboquivari Mountains. No home range studies have been conducted for jaguars in southwestern United States; however McCain and Childs (2008)

used camera-traps to provide the only estimate of one northern jaguar, a minimum observed range of 525 mi².

There are two subspecies of ocelots found in the United States: the Sonoran subspecies (*L. p. sonoriensis*), described by Goldman (1943) with four specimens from southernmost Sonora, and the better-studied Texas subspecies (*L. p. albescens*). Populations of the Sonoran ocelot are isolated from the Texas ocelot by the Sierra Madre highlands (Grigione and others 2007). The population of Texas ocelots is found almost 300 miles south in latitude of the northernmost Sonoran ocelots.

Lopez-Gonzalez and others (2003) conducted surveys throughout Sonora, collecting 36 records of ocelots from ranchers, cowboys, cattle associations, and outfitters. They plotted record localities on habitat maps finding that 75% were associated with subtropical thornscrub, tropical deciduous forest, and tropical thornscrub; 92% of records were within an elevation range of 820 to 3773 ft. The most northerly record of a breeding population was 30°30' in latitude. The authors found only one record of a kitten, in southern Sonora, and a few ocelots were recorded in oak woodlands, all males (Lopez-Gonzalez and others 2003).

Objectives

- To build cooperative relationships with private landowners in Sonora and Arizona to facilitate research and establish corridors connecting patches of continuous habitat throughout the region.
- To survey and inventory land mammal species in the Sky Island region.
- To increase the knowledge about jaguar and ocelot in the Sky Island region.

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrea Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Methodology

Study Area

The Sky Island region of southwestern United States and northwestern Mexico consists of isolated mountain ranges separated by deserts and grasslands. It mixes elements from five major ecosystems: the Rocky Mountains, Sierra Madre Occidental, the Sonoran and Chihuahuan deserts, and the Neotropics. Some Neotropical species, such as the jaguar, ocelot, and coati (*Nasua narica*), reach their northernmost ranges here (fig. 1).

We initiated landowner outreach and surveys in northern Sonora in 2005 to establish partnerships in the region. We used habitat models to ground-truth the predicted corridors for jaguars and ocelots (Boydston and Lopez-Gonzalez 2005; Hatten and others 2003; Menke and Hayes 2003; Menke 2004). We placed a total of 48 remote cameras in select locations in Nogales, Imuris, and Agua Prieta Municipios in Sonora, and Santa Cruz and Cochise Counties in Arizona (fig. 2).



Figure 1—Biotic influences in the Sky Islands.

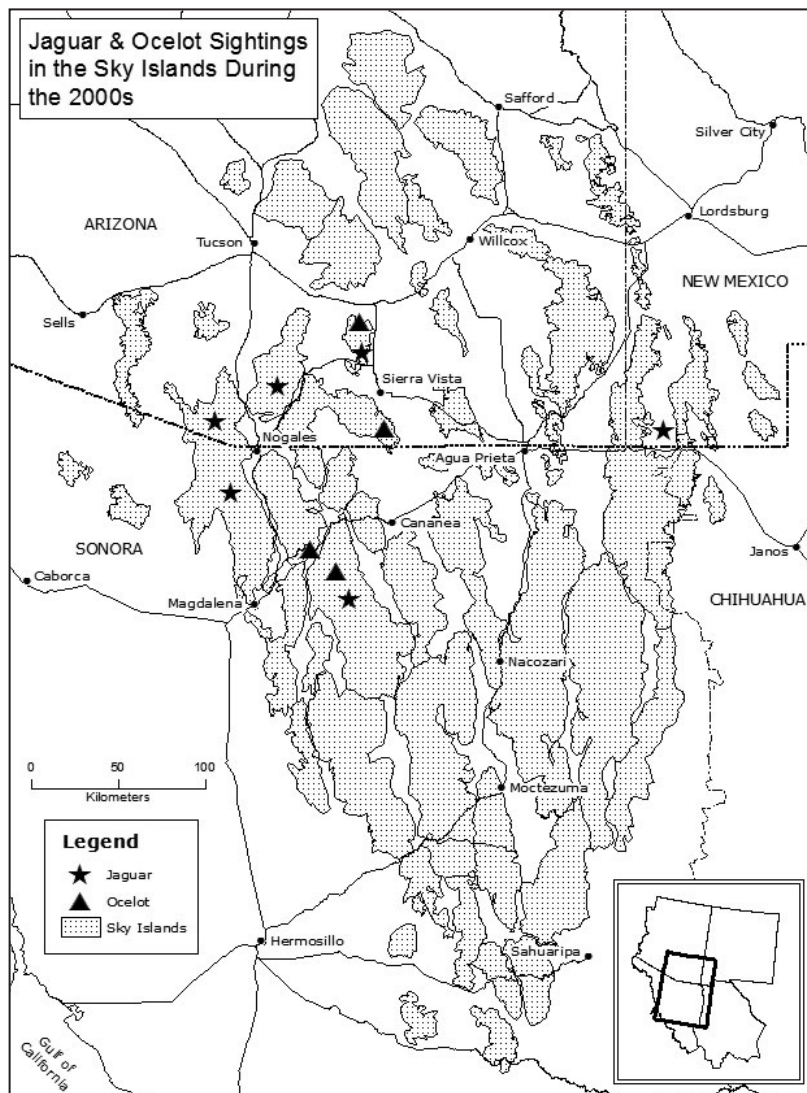


Figure 2—Sky Island Ranges. Camera locations include Sierra La Esmeralda, Cibuta and Azul mountain ranges, the Cocospera River and San Bernardino Valley in Sonora, and the Atascosa, Patagonia, Whetstone, Dagoon and Mule Mountains in Arizona (map by Alex Smith, 6/20/2012).

Table 1—Camera Locations by County or Municipio.

Municipio or County, State	Number of cameras	Landownership (Private/public)
Nogales, Sonora	10	Private
Agua Prieta, Sonora	10	Private
Imuris, Sonora	15	Private
Santa Cruz, AZ	5	Private/Public
Cochise Co., AZ	8	Public

We adopted a standardized remote camera protocol described in Chavez and Ceballos (2006). Remote cameras are non-invasive tools useful for the study of rare, protected or elusive animals (Karanth and Nichols 1998; Medellin and others 2006). We used DeerCam, Cuddeback and Covert DLC cameras that were set to display time and date on the photographs (table 1).

Given the low density of jaguars and ocelots in their northern extent (Brown and Lopez-Gonzalez 2001), camera sites were chosen to maximize the probabilities for photographing felids, instead of a randomized sampling design. We collected ocelot photographs from February 2007 to April 2011, and plotted the relative frequency of events over annual and daily cycles to estimate activity patterns.

Results

Our photographic records include 24 species of wild mammals in five orders: Marsupialia, Rodentia, Lagomorpha, Carnivora and Artiodactyla.

Sonoran Ocelot

We collected 69 records of live ocelots and four of killed ocelots. Our remote camera photographs (60 photographs, 54 events) were taken at elevation ranges between 4185 and 5330 ft. in Madrean evergreen woodland. A majority of photographs was taken in Sonora's Sierra Azul 30 miles south of the international border. Only one photograph was taken in Arizona, in the Whetstone Mountains, almost 40 miles north of the border. These records confirm the northernmost breeding population of Sonoran subspecies at 30°50' of latitude—the first reliable ocelot record in Arizona in 45 years—and an ocelot walking on fresh snow (fig. 3). Our "live" ocelot documentations include at least two males, one female, one kitten, and two of undetermined gender (table 2).

Analyses of the relative frequencies of 54 photographic events on 24-hr cycles confirm the ocelots' nocturnal activity patterns, with peaks of activity between 4:00 and 5:00 and between 20:00 and 0:00. The nocturnal activity patterns of ocelots were similar to those in Texas where activity peaked between 20:00 and 05:00 (Grigione and Mrykalo 2004; Yates 2008). Ocelots were mostly active from late winter to early foreshummer (December to May; Yates 2008). Ocelot daily and annual activity patterns are shown in figs. 4 and 5.

Northern Jaguar

We found records of four jaguars in the United States in the 2000s, three confirmed with photographs. A jaguar named "Macho B" was



Figure 3—Sonoran ocelot. Sonoran ocelot walking on fresh snow in the Sierra Azul, February 2008.

Table 2—Ocelot records in the Sky Islands in the 2000s.

Number of records	Description	Municipality, State (Year)
1	Live animal in cage (photo)	Imuris/Magdalena, Sonora (2007)
2	Poached animals (carcass)	Imuris, Sonora (2007)
2	Road kill Highway 15, Sonora (photo)	Imuris, Sonora (2008)
	Road kill Highway 60, Arizona (photo)	Superior, Arizona (2010)
3	SIA tracks sets	Imuris, Sonora (2007, 08, 09)
65 photos	SIA's 53 photographic events	Imuris, Sonora (2007-2011)
	SIA's 1 photographic event	Cochise County, Arizona (2009)
	AZGFD reported sightings	Cochise County, Arizona (2011, 12)

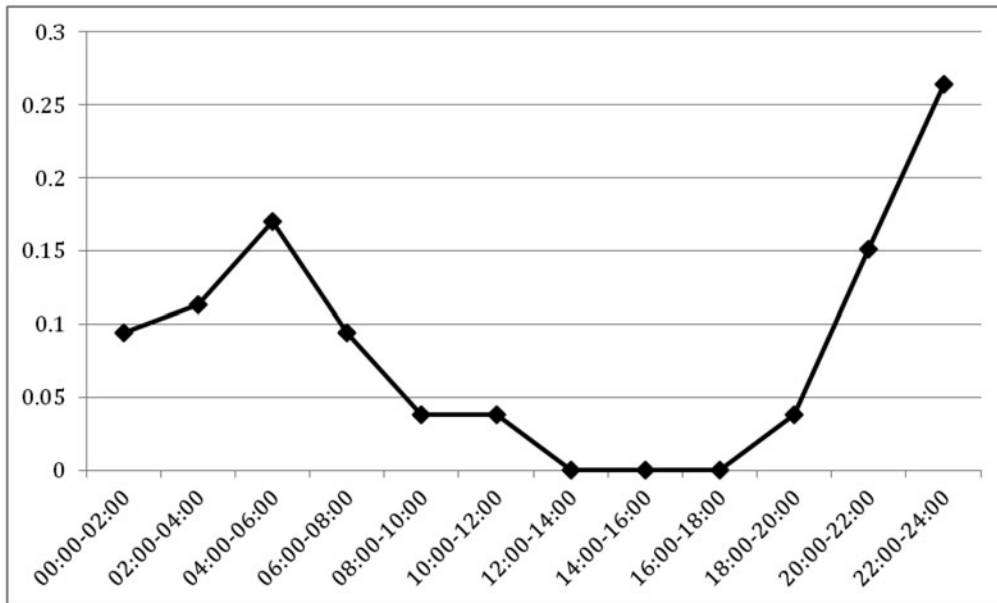


Figure 4—Ocelot daily activity patterns. Ocelot relative frequencies of 54 photographic events over 24-hr cycles.

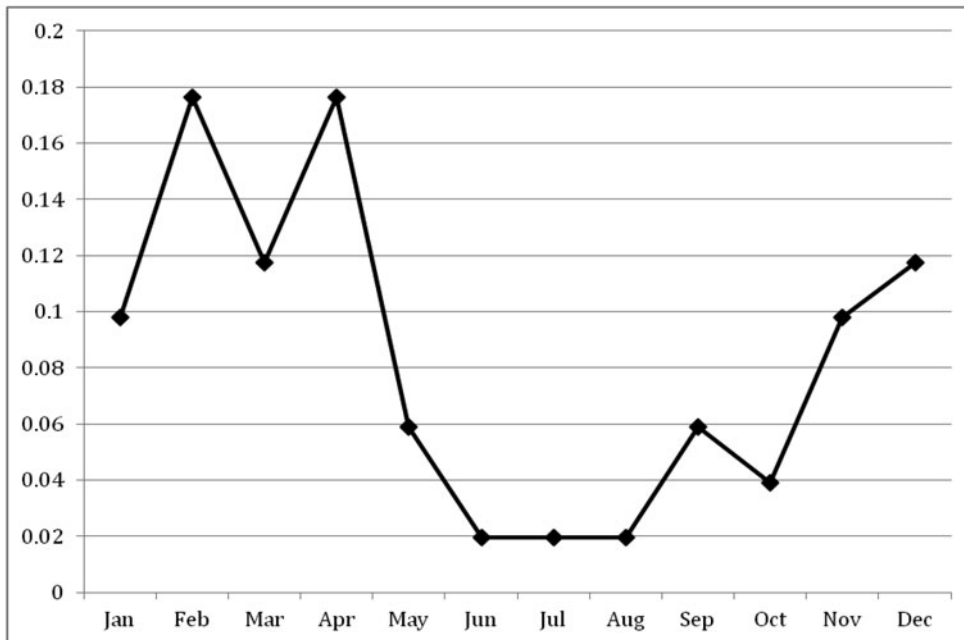


Figure 5—Ocelot annual activity patterns. Ocelot relative frequencies of 52 photographic events over 12-month period.

monitored in Arizona from 1996 (McCain and Childs 2008) until his death in 2009. Another jaguar was photographed in the Animas Valley in 2005 (Warner Glenn, personal communication). In June 2011, a U.S. Border Patrol pilot reported a jaguar in the Santa Rita Mountains approximately 40 miles north of the border. In November 2011, the Arizona Game and Fish Department (AZGFD) confirmed a jaguar sighting in the Whetstone Mountains, approximately 40 miles north of the border.

During this study we photographed two different jaguars (fig . 6) in 2010 and 2011 in the Sierra Azul, and identified two track sets in Sierra Cibuta (2005) and Sierra Azul (2009). Our photographic records were collected in Madrean evergreen woodland at elevation between 4430 and 4590 ft. All photographs were taken between 18:00 and 6:00 hrs. The small sample size of photographs might not truly indicate activity patterns of northern jaguars. Jaguar records in the Sky Islands in the 2000s are shown in table 3.

Discussion

Landowner involvement is critical for long term conservation in private lands of northern Sonora. Haines and others (2006) emphasize the importance of protecting private lands for ocelot conservation. Landowner outreach is an investment that pays off with landowner buy-in, access, local knowledge, and sharing of anecdotal information.

As a result of our outreach and research collaboration in Sonora, a 10,000-acre private ranch called El Aribabi received a Certificate of Voluntary Land Conservation by Mexican agency CONANP in 2011, thus constituting the most recent wildlife reserve in northern Mexico.

Ocelot habitat characteristics such as elevation, vegetation type, and vegetation cover found in this study contrast with those described in Lopez-Gonzalez and others (2003). The authors found ocelots associated with tropical or subtropical habitats, mostly in the southern half of Sonora. The localities where we documented ocelots in northern Sonora are typical Sky Island habitat. We confirmed the northernmost breeding population of Sonoran ocelots in the Sierra Azul Mountains in Madrean evergreen woodlands. The elevation ranges and latitude at 30°50' are above those recorded by Lopez-Gonzalez and others (2003). Additionally we found the first reliable ocelot record in Arizona in 45 years in the Whetstone Mountains at 5330 ft. of elevation (Grigione and others 2007).

The location of a breeding population 30 miles south of the international border, suggests that ocelots could travel northward and currently reside in southern Arizona. The estimated dispersal distances for Texas ocelots (3 to 20 miles; Caso 1994; Crawshaw 1995) are less than those between the breeding population in northern Sonora and sighting locations in Arizona (approximately 50 miles).

The AZGFD reported a road-killed ocelot near Superior, Arizona, and confirmed it to be of wild origin (De Young and Holbrook 2010). This animal might represent the northernmost record for the species,



Figure 6—Northern jaguar. Northern jaguar photographed in Sierra Azul, January 2010.

Table 3—Jaguar records in the Sky Islands in the 2000s.

Number of records	Description	Municipality, State (Year)
11 photos	Warner Glenn (photo)	Animas Valley, NM (2005)
	SIA's 9 photographic events (2 individuals)	Imuris, Sonora (2010-2011)
	AZGFD (photo)	Cochise Co., Arizona (2011)
Undetermined ~100 photos)	McCain and Childs (photos)	Santa Cruz and Pima County, Arizona (1996-2009)
	2	SIA track set SIA track set
1	AZGFD/Border Patrol report	Pima County, Arizona (2011)

north of the Sky Island region. We estimate the distance between Superior to the border, to the Huachuca or to the Whetstone Mountains to be over 120 miles. It is highly probable that ocelots in northern Sonora and southern Arizona—only 70 miles apart—are connected by migration corridors and potentially represent an established trans-boundary population. However, in the case of the documentation near Superior, travel from northern Sonora seems unlikely.

Our data on jaguars is scarce; however, it includes photographs of two different males and a track set potentially expanding the known range of Macho B. We believe our data are inconclusive in terms of daily or seasonal activity patterns.

In 5 years of monitoring public and private lands along the border, we did not find any anecdotal or reliable records of jaguarondi (*Herpailurus yaguarondi*).

Conclusion

The lack of scientific information on Sonoran ocelots, other than historic localities and habitat associations, is evident in the USFWS Draft Recovery Plan. Results from this study increase the knowledge of Sonoran ocelots. The localities where we documented ocelots in Sonora are typical of Madrean Sky Islands and differ from those documented before.

Grigione and others (2007) suggest that conservation of peripheral populations, such as ocelot and the jaguar's northernmost range, plays a role in maintaining the genetic viability of a species. It is essential that source populations of jaguars and ocelots be located and travel routes be identified. Both montane corridors and riparian areas appear to be important travel routes for Neotropical felids.

The importance of trans-boundary conservation cannot be over-emphasized for felids and other species. It is critically important to consider jaguar and ocelot's recent presence in mountain ranges near the border and the connecting linkages in order to protect enough habitat for the establishment of future populations (Grigione and others 2007). The most distant portions of species' distributions are often the last refuge for their survival (Lopez Gonzalez and others 2003). The northern extent of the ocelot's range in southeastern Arizona could prove to contain enough suitable habitat, connective linkages, and prey species to support a breeding population.

The Sonoran ocelot has been given the least amount of attention in scientific research and conservation planning, plainly contrasting with information on the Texas subspecies. This lack of information could lead to inappropriate decisions for recovery, as different types of habitat, elevation, and vegetation cover are found in its northernmost distribution ranges. We believe there are clear differences between the two ocelot subspecies and their needs, with the northernmost population of Texas ocelots found in latitudes almost 300 miles south of the Sonoran ocelots. Due to unique topographic, bio-geographic and climatic features that occur in northern Sonora and southern Arizona, the Sky Island region also represents a distributional extreme with important genetic and adaptive resources that can characterize peripheral populations (Grigione and others 2007).

To support the recovery of endangered tropical felines in the Sky Island region, migration corridors that link key habitat cores in Mexico and the United States must be identified and protected. In southern Arizona, large tracts of protected public lands already exist, including National Wildlife Refuges, National Monuments, Wilderness and

National Conservation Areas. Opportunities for habitat protection south of the border exist, with Sonora being the second largest state in Mexico, and having low human population densities (Lopez-Gonzalez and others 2003). Relatively intact patches of continuous habitat make this area a stronghold for the ocelot.

Border security activities represent the greatest threat to jaguar and ocelot recovery in the United States. Habitat connectivity across the border remains highly threatened by construction of an impermeable barrier and its related infrastructure along the border. The construction of border infrastructure negatively impacts species that live in the region, endangered or otherwise. Division of otherwise continuous habitat by a physical barrier blocks the natural movements of species whose distribution in the United States is already limited, confining them to isolation and potential extinction (Córdova and De la Parra 2007).

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Analysis of the Seasonal Activity Rate of Sympatric Carnivores and their Prey in Saguaro National Park

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Abstract—We investigated the monthly activity rates of bobcats (*Lynx rufus*), gray foxes (*Urocyon cinereoargenteus*) and four of their potential prey species, antelope jackrabbits (*Lepus alleni*), black-tailed jackrabbits (*Lepus californicus*), desert cottontails (*Sylvilagus audubonii*) and eastern cottontails (*Sylvilagus floridanus*), in Saguaro National Park using remote camera trap data. We analyzed images taken over an 11-month period and over 10,000 camera nights and compared the time of day, month, and location of photographs of bobcats, gray foxes and four lagomorph species. Our findings suggest that bobcats and gray foxes are successful sympatric species for much of the year; but during the autumn and winter seasons gray fox activity increased as a result of reduced food availability. Lagomorph activity also changed in the winter; when both jackrabbit species and desert cottontail rabbit activity decreased, while eastern cottontail activity increased, in a manner that was quite similar to that of gray foxes. Lagomorph activity may be influenced by the activity of their predators. Knowledge of how mammals utilize the landscape of Saguaro National Park will enable wildlife managers to implement more effective conservation and management strategies.

Introduction

Sympatry among animals has become more prevalent due to habitat loss, urbanization, and expansion of natural distributions (Chamberlain and Leopold 2005). Sympatry often results in competition among animals due to the use of shared resources. Niche segregation of resources can occur in areas where sympatry is pronounced. Fedriani and others (1999) found that three sympatric carnivores—Iberian lynx (*Lynx pardinus*), Eurasian badger (*Meles meles*), and red fox (*Vulpes vulpes*)—altered their activity patterns to avoid overlap in resource utilization. The potential for competition among species that overlap in geographic range is increased when species are comparable in body size and engage in similar feeding habits (Barrientos and Virgós 2006). In the Sky Island region of southern Arizona, two sympatric carnivore species—bobcat (*Lynx rufus*) and gray fox (*Urocyon cinereoargenteus*)—consume similar prey species such as lagomorphs and ground dwelling rodents (Fritzell and Haroldson 1982; Larivière and Walton 1997). Bobcats and gray foxes inhabit relatively similar environments. In Arizona, these two species can be found in mixed forests, rocky outcrops, and brush areas from elevations up to 3,000 m or more (Tekiel 2008).

One such area in the desert southwest where bobcats and gray foxes co-occur is Saguaro National Park in Tucson, Arizona. Both species

are prevalent within the park, where Benton and others (unpublished data) found that their temporal and spatial distributions overlap extensively. Riley (2006) argues that bobcats are more affected by proximity to urbanization than gray foxes. Gray foxes have often been documented entering developed areas and their home ranges typically occupy urban locations whereas bobcats rarely enter developed areas and have been shown to avoid crossing paved roads (Riley 2006). These patterns are likely caused by differences in diet and the social system of the species. Although gray foxes and bobcats tend to prey on small rodents, bobcats are strictly carnivorous whereas gray foxes are omnivorous (Riley 2006). Riley (2006) states that this more flexible use of the landscape allows gray foxes easier access to increased resources and habitat whereas bobcats' sensitivity has put them at risk to decreased viability in urban-protected zone interfaces. The trend described by Riley (2006) does not apply in Tucson, Arizona, where bobcats are found not only in the wilderness areas of Saguaro National Park but also in adjacent neighborhoods and deeper into the suburban sprawl of the community (Haynes and others 2010). The large population of mountain lions in Saguaro National Park may be influencing the movement of bobcats into urban areas and could be one indication as to why so few bobcats are seen on wildlife cameras. While coyotes have been shown to kill gray foxes (Neale and Sacks 2001), the interactions between these canid species may not be as severe as the interactions between felid species in Saguaro National Park. The interspecific relationships of apex predators and mesopredators impact the behavior of animals at every trophic level; therefore, it is important to understand these patterns in order to appropriately manage and conserve mammalian wildlife.

Antelope jackrabbits (*Lepus alleni*), black-tailed jackrabbits (*Lepus californicus*), desert cottontails (*Sylvilagus audubonii*), and eastern cottontails (*Sylvilagus floridanus*) are commonly occurring lagomorphs found in Saguaro National Park. Although the park has not collected a

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

specimen to confirm the identity of the eastern cottontail, this species is most likely to be the cottontail that is often observed at higher elevations in the park (Swann 2011). The temporal and spatial distributions of these species demonstrate their sympatry and overlaps in activity with bobcats and gray foxes (Benton and others, unpublished data). The lagomorphs of Saguaro National Park are herbivorous species whose diet consists of green plants and some cactus fruits in spring and summer and other woody plants and berries in winter (Tekiela 2008). These lagomorphs inhabit similar areas ranging from deserts and grasslands to woodland thickets (Tekiela 2008).

The Sonoran desert experiences five seasons every year. Foresummer in May and June, when this study began, brings high temperatures, low humidity, and typically no rain. Most plants and animals are dormant during this time, due to the lack of available surface water (Phillips and Comus 2000). The summer monsoon season—early-July through mid-September—is distinguished by high temperature, high humidity, and frequent thunderstorms and corresponds with the second and main growing and flowering season for much of the plant community (Phillips and Comus 2000). Autumn—October and November—is typically warm, with low humidity and very little rain and triggers the growing season of the annual plant community (Phillips and Comus 2000). Winter—December and January—is characterized by mild temperatures and sunny days and gentle rains (Phillips and Comus 2000). Spring—early February through April—when this study was completed, is characterized by mild temperatures and little rainfall, and accounts for the first flowering season of the year (Phillips and Comus 2000). The differences in the availability of flowers, grasses, and fruits to gray foxes and lagomorphs during each season in the Sonoran desert may influence the rate of activity of these species as well as the rate of activity of their conspecifics and predators.

The goal of this study was to determine whether bobcat and gray fox activity in Saguaro National Park differs during certain periods of the year based on dietary differences. Additionally, we were interested in how bobcat and gray fox activity affects the seasonal activity of lagomorphs. We tested several hypotheses using images from wildlife cameras that were captured by a Saguaro National Park wildlife camera program conducted from May 2011 through March 2012. We predicted that the activity patterns of bobcats and gray foxes would be similar during the foresummer, summer monsoon, and autumn seasons due to their sympatric nature. However, during the winter we predicted that gray fox activity would shift when supplementary food resources, such as fruits, were not available. In addition, we predicted that lagomorph activity would increase during the foresummer, summer monsoon, and autumn when gray foxes have supplementary food sources, and decrease in late autumn and winter when fox predation intensifies.

Methods

Study Area

Saguaro National Park is approximately 37,000 ha and is divided into two districts: Rincon Mountain District and Tucson Mountain District (fig. 1). Rincon Mountain District (RMD) lies 32 km east of the center of Tucson and is the larger of the two districts. Elevation ranges from 664 m to 2,641 m and the dominant plant communities include thorn-scrub, chaparral, grasslands, and temperate coniferous forests. Tucson Mountain District (TMD) lies 24 km west of the center of Tucson and ranges in elevation from 668 m to 1,498 m. Dominant

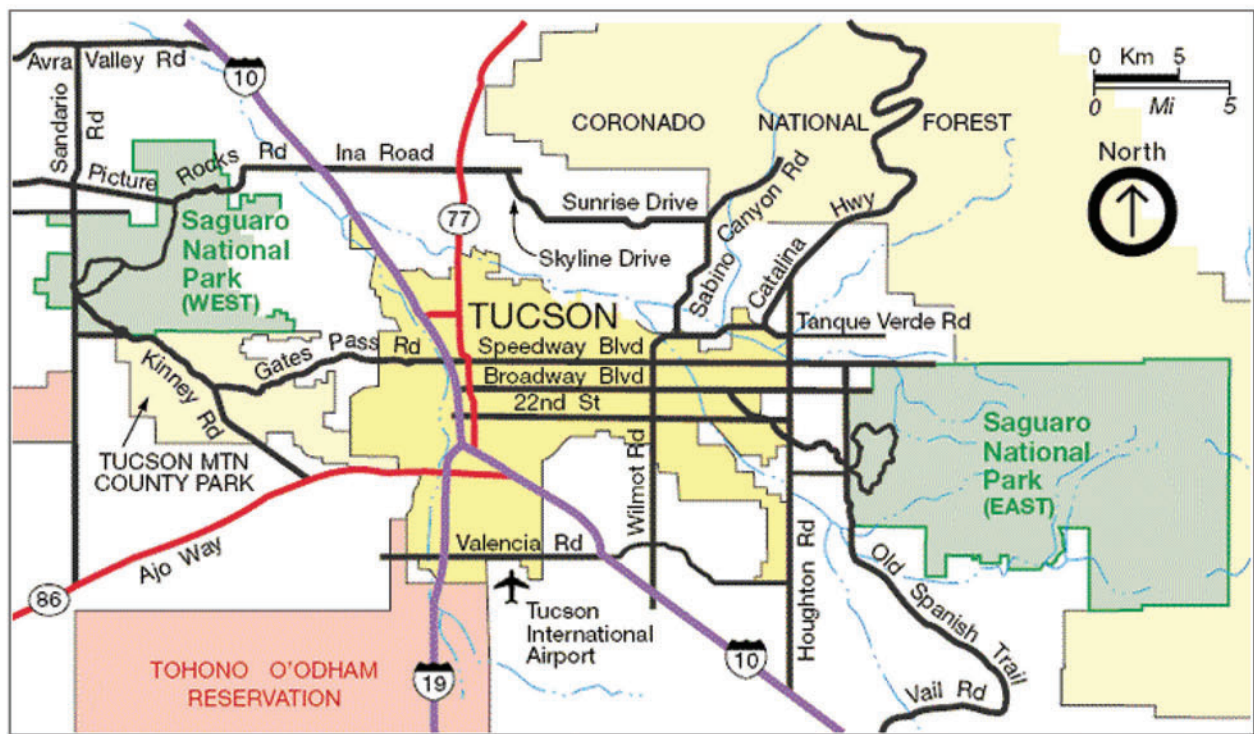


Figure 1— Map of Saguaro National Park in Tucson, Arizona. The distance between the Rincon Mountain District (east) and the Tucson Mountain District (west) is 24 km.

plant communities include those that are characteristic of the Sonoran desert ecosystem.

Data Collection

Saguaro National Park began a year-long study in May 2011 using wildlife cameras to determine species richness and species occupancy within the park. Saguaro National Park made these data available to us for use in better understanding the monthly activity rates of bobcats, gray foxes, and lagomorphs. The park used *Cuddeback Capture* units, white flash heat, and motion sensor digital wildlife cameras under a study design where both districts of the park were divided into 1-km² plots using a grid feature in the Hawth's tool set of ArcMap, a geospatial processing program. Plots were randomly located and distributed among four elevation gradients: 0-914 m, 914-1,524 m, 1,524-2,134 m, and greater than 2,134 m. Any plot containing more than 50% land outside the park boundary was removed from the data set. The steeper Rincon Mountain District (RMD) was divided into four strata, while the Tucson Mountain District (TMD) was divided into two strata. Fifteen plots were chosen in each stratum using a random selection tool in Hawth's tools. Camera locations were randomly selected using ArcMap as well. On a rotational basis, two plots in each stratum had four cameras set, no less than 200 m apart, for periods of 6 weeks. The strategy to keep the camera points random, without human bias, was to place them within 20 m of the randomly selected coordinate. The study resulted in a total of 10,338 camera nights throughout Saguaro National Park, including 3,527 nights in strata 1; 3,361 nights in strata 2; 1,652 nights in strata 3; and 1,798 nights in strata 4 (66.4% of these nights were in the Rincon Mountain District and 33.6% in the Tucson Mountain District). For personnel and camera safety, we occasionally used alternative random points (e.g. if the point fell on the side of a cliff). Cameras were set using metal stakes and nylon straps, and were placed as close to the random points as possible in

an open area in hopes of increasing the probability of detection of an animal if it was present. The cameras were programmed to sense heat and motion at a 14° angle from the IR sensor, up to a distance of 10 m. The date and time were programmed on each camera and a 30-second timer was engaged, meaning that when the camera detected movement and a difference in heat gradient, a photograph would be captured every 30 seconds.

Approximately every 2 weeks, resource management staff and volunteers checked each camera to collect images, solve troubleshooting issues, replace batteries, and assure camera placement was still intact. Photos were extracted from SD cards and downloaded to an MP3 player for backup. These data were then brought back to the office to save images and ensure data security, enter data, and analyze photos. The date, time, location, species, and number of individuals associated with each photo were recorded into the park's wildlife camera database. The captured images were analyzed using graphs to observe patterns and trends.

This study was solely descriptive as we searched for patterns in activity between bobcats, gray foxes, and their potential prey animals. First, we summarized monthly numbers of photographs of bobcats, gray foxes, and lagomorphs. Total capture numbers for each species were not equivalent; therefore, we standardized monthly activity rates using proportions of photographs. Figure 2 illustrates a total of 257 gray fox images, compared to 67 bobcat images. Figure 3 demonstrates a total of 959 desert cottontail images; compared to 62 eastern cottontail images, 342 antelope jackrabbit images, and 495 black-tailed jackrabbit images. Each month's number of captures was divided into the total number of captures for that species to create the y-axis proportion of photographs. This method allowed for efficient visual representation of patterns between our focal species. Graphing the monthly activity of bobcats, gray foxes, and lagomorphs allowed us to explore potential explanations for differences in mesopredator activity during specific seasons or months.

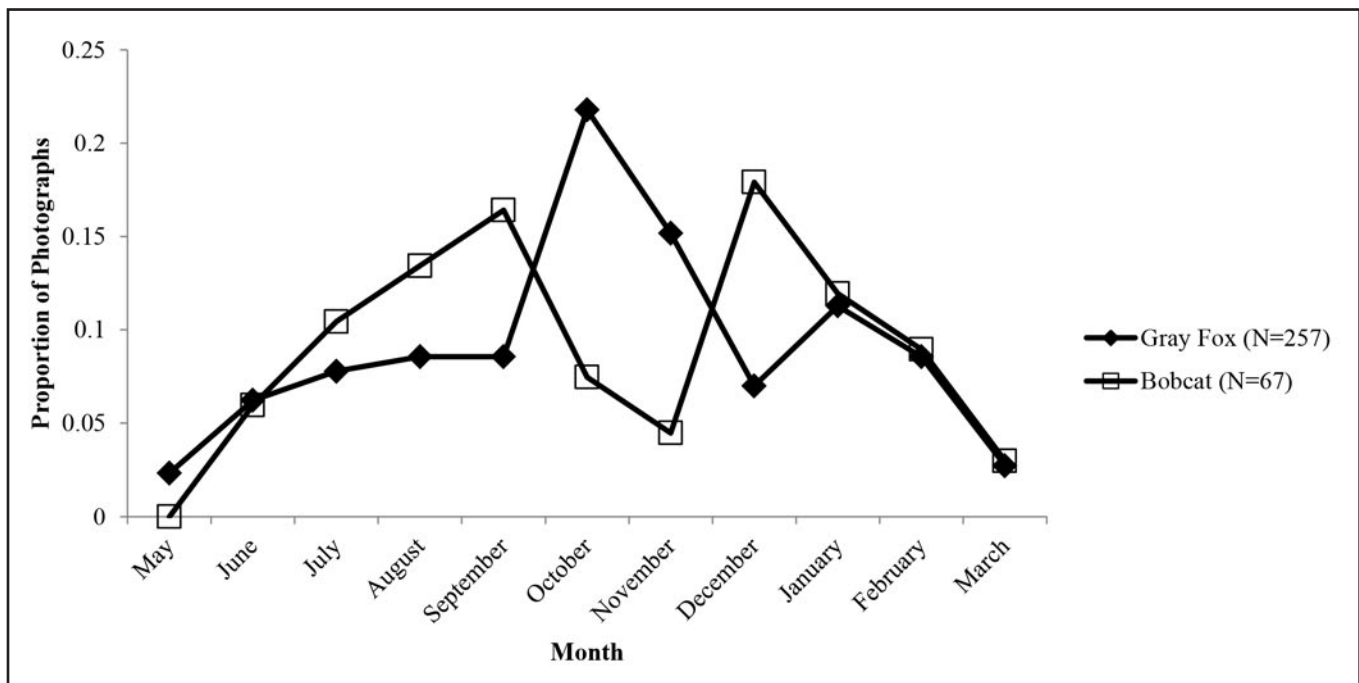


Figure 2— Monthly activity rate of bobcats and gray foxes in Saguaro National Park as determined by proportion of photographs.

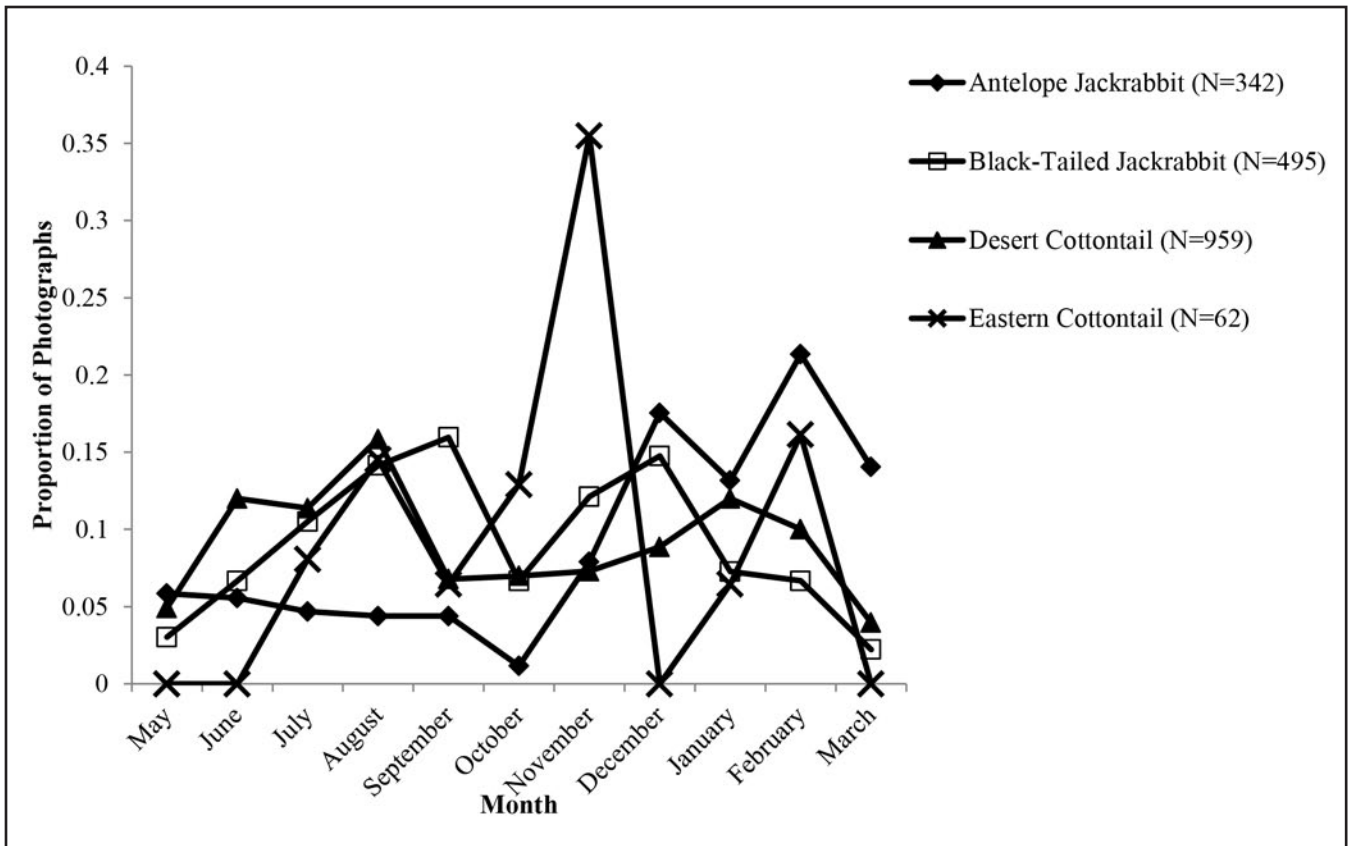


Figure 3—Monthly activity rate of lagomorphs in Saguaro National Park as determined by proportion of photographs.

Results

The total number of images of bobcats, gray foxes, and four lagomorph species captured over an 11-month period in Saguaro National Park were organized in table 1. As demonstrated in figure 2, activity of gray foxes was relatively low beginning in the foresummer when the study began and remained low throughout the summer monsoon season. Activity rates of gray foxes increased dramatically in the month of October, but decreased from November through March. Figure

2 also illustrates that bobcat activity was high from May through September, but decreased dramatically in October and November, before peaking again in January and decreasing between January and March. Figure 3 shows that black-tailed jackrabbit activity patterns mimic those of bobcats very closely. Black-tailed jackrabbit activity was high from May through September, before decreasing dramatically in October, then peaking again in December and decreasing from December through March. Desert cottontail rabbit activity was also high during the foresummer and part of the summer monsoon

Table 1—Monthly activity rates of bobcats, gray foxes, desert cottontails, eastern cottontails, antelope jackrabbits, and black-tailed jackrabbits in Saguaro National Park as determined by proportion of photographs taken between May 2011 and March 2012

Month	Bobcat	Gray Fox	Desert Cottontail	Eastern Cottontail	Antelope Jackrabbit	Black-tailed Jackrabbit
May	0	6	47	0	20	15
June	4	16	115	0	19	33
July	7	20	109	5	16	52
August	9	22	152	9	15	70
September	11	22	65	4	15	79
October	5	56	67	8	4	33
November	3	39	70	22	27	60
December	12	18	85	0	60	73
January	8	29	115	4	45	36
February	6	22	96	10	73	33
March	2	7	38	0	48	11
Total	67	257	959	62	342	495

season, before decreasing in September. Unlike black-tailed jackrabbit activity, desert cottontail activity did not increase again in the winter, but rather it remained relatively low throughout the autumn, winter, and spring seasons. Antelope jackrabbit activity was low and constant throughout the foresummer and summer monsoon and their activity was nearly undetectable in October before increasing between the months of October and March. During the foresummer, eastern cottontail activity was undetectable. In July and August eastern cottontail activity increased, before going down in September and spiking substantially in November. Immediately following the spike in activity in November, eastern cottontail activity was undetectable in December. From January to February eastern cottontail activity increased before it was undetected again in March.

Discussion

By capturing images of bobcats and gray foxes in the same areas at approximately the same times, our results indicate that bobcats and gray foxes are sympatric carnivores in Saguaro National Park for a large portion of the year; however, as seen in figure 2, gray fox activity increased dramatically from September to November before dropping off in December. We predicted this shift in activity was the result of the differences in the dietary constraints of bobcats and gray foxes. These results support our hypothesis that gray foxes alter their activity when utilizing alternate food sources such as grasses and fruits to supplement their diet of prey animals. Gray fox activity is lower in warmer months of the year because they have additional food sources such as manzanita fruit (Neale and Sacks 2001). Scat analyses suggest that fruit comprises 45-60% of gray fox diet in the foresummer, summer monsoon, and autumn months of the year and only about 15% of their diet in the winter and spring (Neale and Sacks 2001). Rodents and lagomorphs make up 15-30% of gray fox diet in the warmer months of the year and 45-50% of their diet in the winter and spring. Bobcat activity remains relatively constant throughout the year because their diet is limited to the consumption of meat; 50-60% of bobcat diet consists of rodents and lagomorphs in the summer monsoon and autumn, but during the winter the percentage of rodents in the diet decreases and lagomorphs increases from around 5% in the autumn to 15% in the winter (Neale and Sacks 2001). Prey selection in bobcats may shift as temperatures decrease due to a reduced amount of desert squirrel and rodent activity during colder months when they store food and remain in their burrows throughout the winter (Phillips and Comus 2000).

We found some support for our hypothesis that lagomorph activity would decrease in late autumn and winter (fig. 3) when gray fox activity increased. Although black-tailed jackrabbits and desert cottontails exhibited generally similar patterns of behavior across the 11-month study, desert cottontail activity was high in the summer monsoon, low during October-December, and then increased slightly in January before decreasing in the spring. Black-tailed jackrabbit activity was high in the foresummer and summer monsoon, but dropped in the autumn and increased during the winter, before it decreased again in the spring. Antelope jackrabbit activity was low and constant through foresummer and summer. Beginning in October, antelope jackrabbit activity began to increase and between October and December 2011, the amount of activity doubled. This increase was short-lived, before it dropped to a more stable amount in the spring. We hypothesized that the change in lagomorph activity during the autumn months may be the result of an increase in gray fox predation (fig 4). The desert cottontail may have been more impacted by the change in gray fox activity during autumn compared to antelope and black-tailed jackrabbits. The desert cottontail was the only lagomorph species found at

low elevation that did not return to the same high activity rate seen in the warmer months of the year following its drop in activity in the autumn. Unlike the antelope and black-tailed jackrabbits, desert cottontail activity remained relatively constant at a low rate from October through March. Eastern cottontail activity was undetected in the spring, a pattern that was unique among the lagomorphs analyzed. A gradual increase in activity was then seen from late summer through the fall. A marked increase in eastern cottontail activity was seen only in November 2011. Later in the winter, activity remained relatively high but was more constant. The difference in detection among lagomorphs may be the result of decreased food availability in the forest due to cold temperatures and snow cover. Lagomorph activity in Saguaro National Park changes seasonally, which may be due to surface water availability and food supply. The bimodal periodicity of rain in the Sonoran desert often influences mammalian behavior because water is a limiting resource in this arid environment (Phillips and Comus 2000). It is important to consider this variable when analyzing detection rates of gray foxes, bobcats, and lagomorphs in Saguaro National Park.

In order to ensure that our data analysis was not overly simplistic, we investigated alternative hypotheses for the increase in activity seen in gray foxes between September and December. One alternative explanation is simply sample size: in October 2011 Saguaro National Park hosted the 2011 National Geographic BioBlitz event. This event drew thousands of visitors to both districts of the park, including the back country areas, and many of the wildlife cameras were deployed for educational purposes; resulting in a smaller number of camera nights. This decrease in the number of camera nights overall may have created spurious proportional relationships in the data. The abundances of bobcats and gray foxes differ between the two districts of the park due to differences in habitat type and overall available area. Because this study analyzed the activity of species in both districts of the park, we must account for these differences. TMD has half the elevation gradient as RMD, and as a result, TMD has fewer strata. Each month TMD had fewer camera nights than RMD and in some months there were half as many at TMD compared to RMD. The difference in the number of camera nights is the result of the reduced amount of area available to survey in TMD. The amount of gray fox activity at TMD is higher than RMD even though we had fewer camera nights in TMD. Approximately 53.3% of gray fox images were captured in TMD. The distribution may be influenced by



Figure 4— Gray fox with a desert cottontail in its mouth.

the difference in the amount of sampling conducted in each district, and gray fox activity could potentially be much higher each month than previously thought. Future studies using camera data at Saguaro National Park should account for the differences between districts by analyzing them as separate entities or by standardizing the number of camera nights in each district

Not only did the BioBlitz alter the October 2011 data collection, it may have altered wildlife behavior. The increased human activity of the BioBlitz event may have influenced the behavior of gray foxes within the park and forced them to relocate to more isolated areas where cameras were more likely placed. Based on our photographic results, October 2011 saw the highest amount of gray fox activity and it may have been human influenced. The mere presence of a wildlife camera may also cause gray foxes to alter their behavior. Remote camera trapping did not allow us to identify individuals. Because we can only count activity at a camera, we do not know if the camera is recording the activity of one or 100 individuals. For example, a single animal could be utilizing the same portion of a wash due to its proximity to the animal's den. Park employees have noticed over the years that gray foxes appear to be more curious about wildlife cameras than many other species. One example of this is on a plot in TMD where two gray foxes loitered extensively near a specific camera location, which resulted in numerous photographs of the same individuals.

Conclusions

Our study contributed to the understanding of the coexistence of two sympatric carnivores and some of their prey sources in a Sky Island ecosystem. More data collection and analysis would be possible by marking individuals or analyzing bobcat patterns in order to identify individuals to better understand the population dynamics of each species. Due to the delicate and ever-changing composition of the ecosystem at Saguaro National Park, this study should be continued over many years. An annual study would help to determine if gray fox activity does in fact change in response to differences in food availability at different times of the year or if the activity is more greatly influenced by external factors like annual precipitation. In addition to an annual study, a more comprehensive analysis of the rodents and lagomorphs should be conducted in order to understand their ecology directly and not just through their predators. Park biologists and

technicians can utilize this data to study the interspecific interactions of mammals in Saguaro National Park and make informed decisions about the management of wildlife species within the park.

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Wildlife Surveys and Monitoring With the Use of Remote Camera Traps in the Greater Oak Flat Watershed Near Superior, Arizona

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Abstract—In September 2011, we initiated a 2-year “camera trap” mammal survey in the Greater Oak Flat Watershed near Superior, Arizona. Our survey area covers a total of 6,475 ha. The area surveyed is primarily a mixing zone of upper Sonoran Desert and interior chaparral, with influences from the Madrean vegetation community. Elevations range from 1150 to 1450 m. Ten cameras were deployed in early October of 2011 and information was gathered and analyzed from that date to April 2012. We located cameras primarily in riparian and xero-riparian drainages. Locations were chosen as logical wildlife corridors to obtain a sampling of wildlife while allowing relatively easy access to cameras for data collection. To date, we have identified 13 mammalian species, including bobcat (*Lynx rufus*), ringtail (*Bassariscus astutus*), and coati (*Nasua narica*).

Introduction

The study focuses on the Greater Oak Flat Watershed east of the town of Superior, Arizona, and approximately 100 km east of downtown Phoenix, Arizona. The survey area is bounded on the west by “Apache Leap,” no more than 1 km north of Highway 60, 1 km east of Gaan Canyon (known as Devil’s Canyon on most maps) on the east and an arbitrary southern limit. The survey area is primarily public land managed by the USDA Forest Service, Tonto National Forest (see fig. 1 for map of the survey area).

Pyroclastic welded tuff, specifically “Apache Leap tuff,” is the most common substrate throughout our study area (USDA Forest Service 2010). These formations create a generally rugged and steep topography with deep canyons and jagged spires and ridges. The watershed is drained by Gaan Canyon, which flows year-round through most of the survey area and by Queen Creek. Previous flora and fauna surveys have shown that Gaan Canyon is botanically diverse and supports a high diversity of bird species (Jacobs 2009). Eleven special status bird species exist within 8 km of the project area according to review tools provided by the Arizona Game and Fish Department (AZGFD). The area surveyed is primarily a mixing zone of upper Sonoran Desert

and interior chaparral, with some influence of Madrean evergreen woodland. The elevation ranges from approximately 1150 to 1450 m.

Interior chaparral vegetation includes manzanita (*Arctostaphylos pungens*), catclaw acacia (*Acacia greggii*), desert broom (*Baccharis centennial*), and scrub oak (*Quercus turbinella*) (Spangle 2008). Other common upland species include hop bush (*Dodonaea viscosa*), birchleaf mountain mahogany (*Cercocarpus betuloides*), jojoba (*Simmondsia chinensis*), wait-a-minute bush (*Mimosa biuncifera*), cholla (*Opuntia* sp.), and agave (*Agave* sp.) (Jacobs Avi). Vegetation composition throughout the uplands is significantly influenced by Arizona Uplands division Sonoran Desert elements as evidenced by the presence of saguaros (*Carnegiea gigantea*), which are fairly common on rocky east- and south-facing slopes.

The primary human uses of the Greater Oak Flat Watershed include recreation, mining, and cattle grazing (Spangle 2008). A mining company is investigating the area for a large underground copper mine and is conducting pre-feasibility drilling. Federal legislation has been introduced to privatize much of the study area to accommodate the construction of a large underground mine. A portion of the Greater Oak Flat Watershed was set aside from mining by executive order in 1955 (Federal Register 1955).

There has been little to no survey of land mammal species in the study area to date and no comprehensive study of human recreational activities in the study area. This study will assist land managers and decision makers in understanding movement, behavior patterns, and distributions of species that use the watershed as well as the use and movement of human recreational activities within the watershed.

Remote cameras are extremely useful for the study of rare, threatened or endangered species, and/or elusive or cryptic animals. In recent years they have been used to evaluate the presence and abundance

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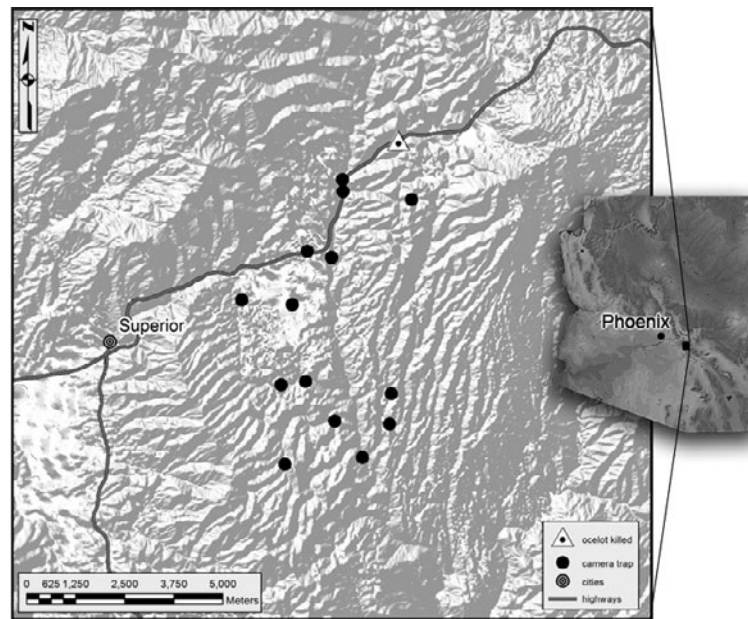


Figure 1—Map of survey region, camera trap locations, and location of road-killed ocelot, Greater Oak Flat Watershed near Superior, Arizona, October 2011-April, 2012.

of jaguars, ocelots, and other mammals (Karanth and Nichols 1998; Avila 2007; McCain and Childs 2008). Remote cameras are a safe, non-invasive technique, and in some cases can provide estimations of wildlife population densities (Silver 2004; Silver and others 2004). In 2007, Sky Island Alliance initiated a remote camera study on cross-border permeability in northern Sonora, Mexico, with the goal of identifying wildlife corridors that connect the northernmost populations of jaguars and ocelots with individuals documented in southern Arizona; the study quickly documented ocelots in Sonora's Sierra Azul (Avila 2007).

Oak Flat and the Ocelot

In 2010 the AZGFD reported a road-killed ocelot (*Leopardus pardalis*) found on Highway 60 east of Superior, Arizona, between Oak Flat Campground and Top of the World, possibly representing the northernmost record for the species. DNA analysis from the U.S. Fish & Wildlife Service's forensic lab shows the ocelot was of wild origin. However, due to lack of additional samples or sequence data from Sinaloa or Sonora, the lab was not able to determine whether the ocelot was of Sonoran origin (De Young and Holbrook 2010).

The ocelot has been associated with a wide range of habitats, including mangrove forests, savannah grasslands, thornscrub, and tropical forests of all types (Lopez-Gonzalez and others 2003). Recent records by Avila (2007) document ocelots in Madrean evergreen woodland, in elevations above 1200 m.

Lopez-Gonzalez and others (2003) emphasize the importance of considering the ocelot's short dispersal distances (5-25 km) when protecting and connecting patches of suitable ocelot habitat. The location of the road-killed ocelot reported by AZGFD is in the interior chaparral vegetation community, at an elevation of 1334 m within the Greater Oak Flat Watershed.

Objectives

Our primary objective was to conduct non-invasive surveys of land mammal species and secondarily to survey human activities in the Greater Oak Flat Watershed. We were interested in gaining baseline data due to future potential habitat destruction from construction and operation of a proposed underground block cave mine in the area. An underground block cave mine would create a void the size of the ore body that leads to subsidence and the altering of water flow patterns (Featherstone 2012).

We conducted a preliminary habitat survey prior to placement of cameras, which indicated sufficient habitat for good land mammal diversity. An initial literature search showed that, to date, no intensive mammal surveys have been conducted in the Greater Oak Flat Watershed.

Methodology

We adopted a standardized remote camera protocol to validate presence/absence of mammal species in a given area (Chavez and Ceballos 2006). The selection of camera sites was chosen carefully to maximize probability for photographing land mammals. We established basic criteria to select camera locations using regional topographic maps, satellite imagery, and GIS surveying for the following variables: topography, geographic connection of mountain ranges, elevation, vegetation type, presence of temporary or permanent water source, and size of corridors (arroyos).

Ten remote cameras are located within a 65-km² study area. We are using Cuddeback Attack IR cameras within lockable bear proof camera safes (Cuddeback 2012). Cameras and safes were supplied at a discount by Cuddeback and we are grateful for their support. The cameras are equipped with 4 GB memory cards to assure ample storage space between camera checks.

After deployment in select areas, cameras were revisited every 4 to 5 weeks, based on battery life and memory card space. We did not use any type of attractants, lure, or bait near our cameras, to avoid species bias or modification of behavior. Cameras are placed with minimal disturbance to the surrounding vegetation, although care is taken to make sure that false triggers from blowing vegetation are kept to a minimum. All remote cameras were set to display time and date on photographs helping us better evaluate daily activity patterns.

Cameras were set to record a still photograph followed by 30 seconds of video. Several cameras have been moved during the course of the survey to date. Potential for damage/theft based on proximity to human activity prompted us to reposition one of our cameras. (A camera was stolen with only one month of data accumulated.) More than one camera was moved due to a lack of mammal activity at the site. As the study matures, we will be better able to gauge whether to move cameras for optimal observation or to leave them in place to record seasonal fluctuations in activity.

In order to manage the numerous photographs in an organized manner, we developed a system for labeling remote cameras, their location, and corresponding memory cards. After each field visit, we collected information on all wildlife species, time and date of each photo-event and observations, including gender, approximate age, health status, number of animals in photo, and behavior, into a database for the purpose of analyzing data systematically.

Both photographs and subsequent 30-second videos were used to tally species numbers. Redundant counts were reduced, such as when an animal stayed in the vicinity and was captured multiple times. However, if good judgment would indicate that more than one individual was present, all were counted, even if all were not in the frame at the same time (e.g. an individual runs across the frame at the beginning of the video and a second individual runs in the same direction later). Different species together (dogs with people or hikers with trucks) generated two records, each counted separately. Skunks and deer were not identified to species for the tallies. People on foot or horseback were counted individually but a vehicle (truck, ATV, motorcycle) was counted as one, regardless of the number of occupants. Birds were recorded, but not counted because their detection

was incidental to this survey. People and domestic dogs that could be identified as the same individuals were counted only once if detected again within 10 minutes. Those returning later in the day, however, were counted again.

Camera locations were grouped into three types of terrain depending on the slope (flat, wide, and narrow) as calculated from a 10-m resolution digital elevation map (DEM) averaged within 25 m and 100 m buffers surrounding each camera location (fig. 2). Flat terrain had slopes of less than 15 percent at both 25 and 100 m, wide canyons are less than 15 percent at 25 m but greater than 15 percent at 100 m and narrow canyons are characterized as having greater than 15 percent of slope at both 25 and 100 m.

“Effort” varied across 15 camera trap locations because cameras were moved or removed during the survey period. The number of camera-days was used to adjust summary statistics for this varying effort. Cameras were in place for a total of 1750 camera-days.

Results

We have identified 13 species of wild mammals, as well as humans and domestic animals, in 15 camera locations (see table of species in table 1). We had 418 detections of wild mammals or 0.24/camera-day of 13 different species (deer were counted as 1 species, striped and hooded skunks were counted as 1 species, table 1). Mean detections of wild mammal individuals across 15 locations was 0.414 ± 0.438 (95% CI) detections/camera-day (range 0.01-3.5).

Sightings per camera broken down by species are shown in figure 3. The greatest variety and number of species were found in the wide canyon group with one location showing as many as 4.5 sightings per day for all species.

We grouped species photographed into four categories: mesocarnivores, herbivores, domestic, and human (including trucks and ATVs). Figure 4 shows the distribution of total species from each category by terrain type. Mesocarnivores included ringtail, raccoon, coyote, coati, bobcat, skunks, and gray fox. Herbivores included squirrels, cottontail,

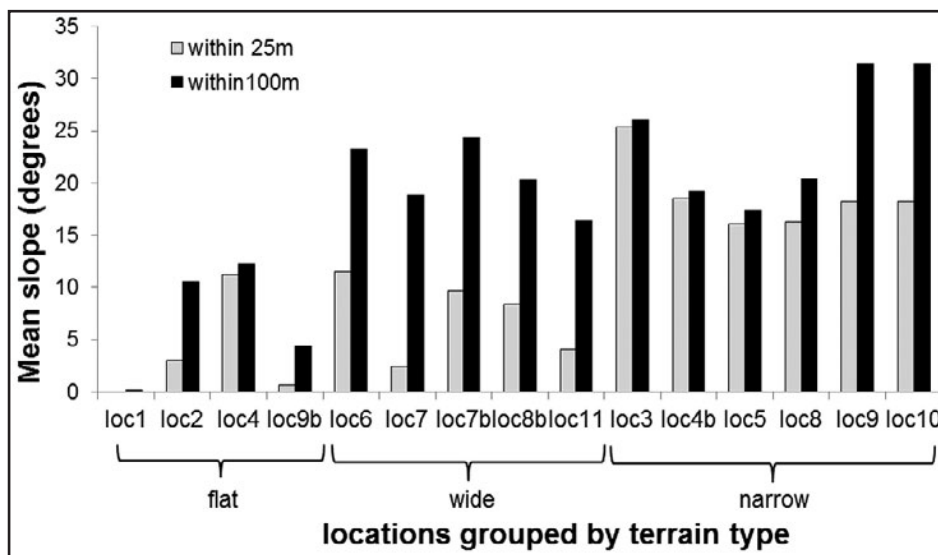


Figure 2—Mean percent slope within 25-m and 100-m circular buffers surrounding each camera location, as calculated from 10-m resolution DEM, Greater Oak Flat Watershed near Superior, Arizona.

Table 1—Species detected by camera traps in Greater Oak Flat Watershed near Superior, Arizona, October 2011-April 2012.

Common name	Genus species
bobcat	<i>Lynx rufus</i>
coati	<i>Nasua narica</i>
cottontail	<i>Sylvilagus audubonii</i>
coyote	<i>Canis latrans</i>
deer	<i>Odocoileus virginianus</i> (white-tailed), <i>O. hemionus</i> (mule)
gray fox	<i>Urocyon cinereoargenteus</i>
javelina	<i>Pecari tajacu</i>
striped & hooded skunk	<i>Mephitis mephitis</i> (striped), <i>M. macroura</i> (hooded)
spotted skunk	<i>Spilogale gracilis</i>
hog-nosed skunk	<i>Conepatus mesoleucus</i>
raccoon	<i>Procyon lotor</i>
ringtail	<i>Bassariscus astutus</i>
rock squirrel	<i>Spermophilus variegatus</i>
domestic dog	<i>Canis familiaris</i>
domestic cat	<i>Felis catus</i>
domestic cattle	<i>Bos taurus</i>

javelin, and deer. Domesticals included dogs, cats, and cattle. Humans included those on foot, on horseback, and motorized vehicles.

Our data indicate that the most common and widely distributed focal species in our study area is the grey fox (*Urocyon cinereoargenteus*). Javelina (*Pecari tajacu*) was the least recorded with only 1 photograph, which may be due to camera bias (tracks of javelina have been noted in the area). Preliminary results indicate that mammal density is highest in wide canyons while both numbers and species richness are lower in narrow/steep canyons. It also appears that bobcat and coyote favor roads for travel despite higher human traffic.

Data collected to date show that human activity is highest in the wider canyons and is the lowest in narrow canyons. The heaviest use by humans occurred in March, while the least was in December (fig. 5).

Discussion

Although this survey’s primary purpose is to study land mammals, the versatility of using camera traps to also record human activities and movements allows us to expand the scope of the survey to also include mapping of human recreational activities such as hiking, rock climbing, and 4-wheel-drive activities. In most cases it is easy

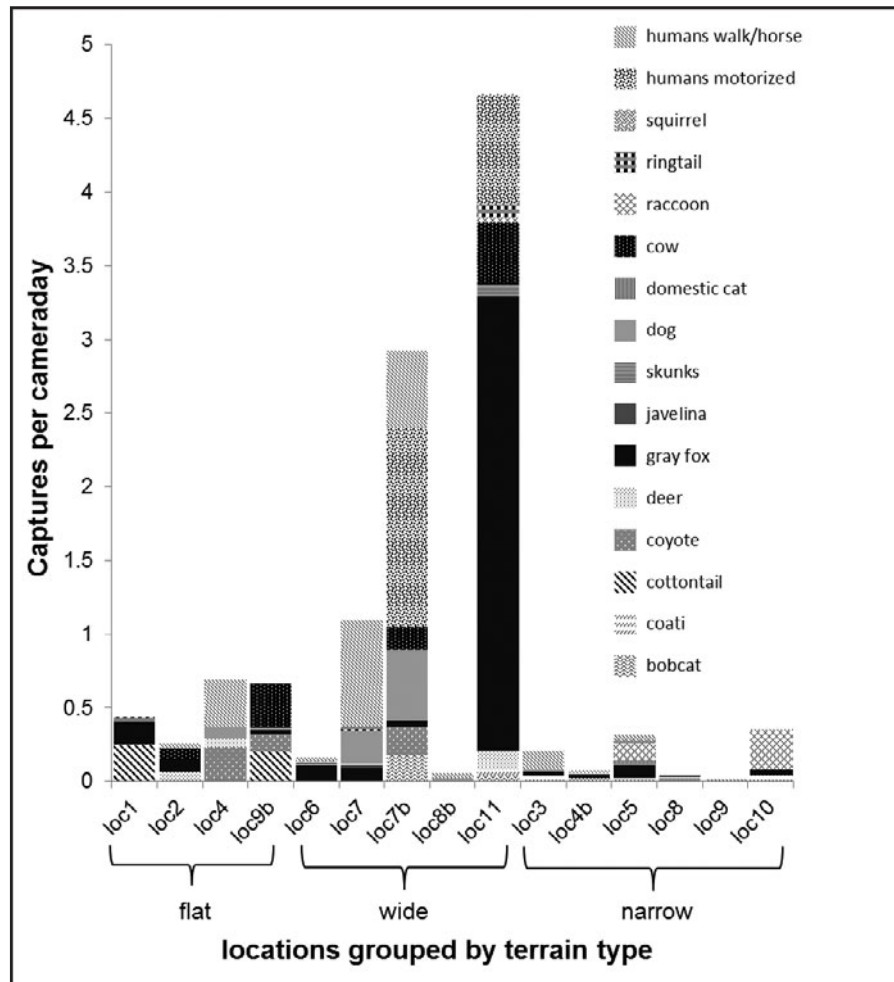


Figure 3—Sittings per camera-day for camera locations, grouped by terrain type. Flat terrain had slopes of <15% within 25 m and 100 m, wide canyons had slopes <15% within 25 m and >15% within 100 m, and narrow canyons had >15% slope within 25 m and 100 m of the camera location, Greater Oak Flat Watershed near Superior, Arizona.

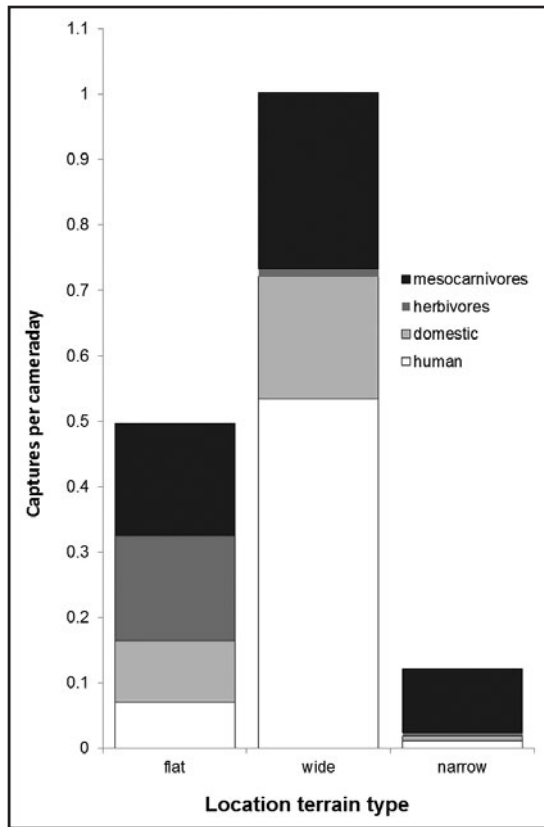


Figure 4—Sittings per camera-day, grouped by mammal type and terrain type, Greater Oak Flat Watershed near Superior, AZ.

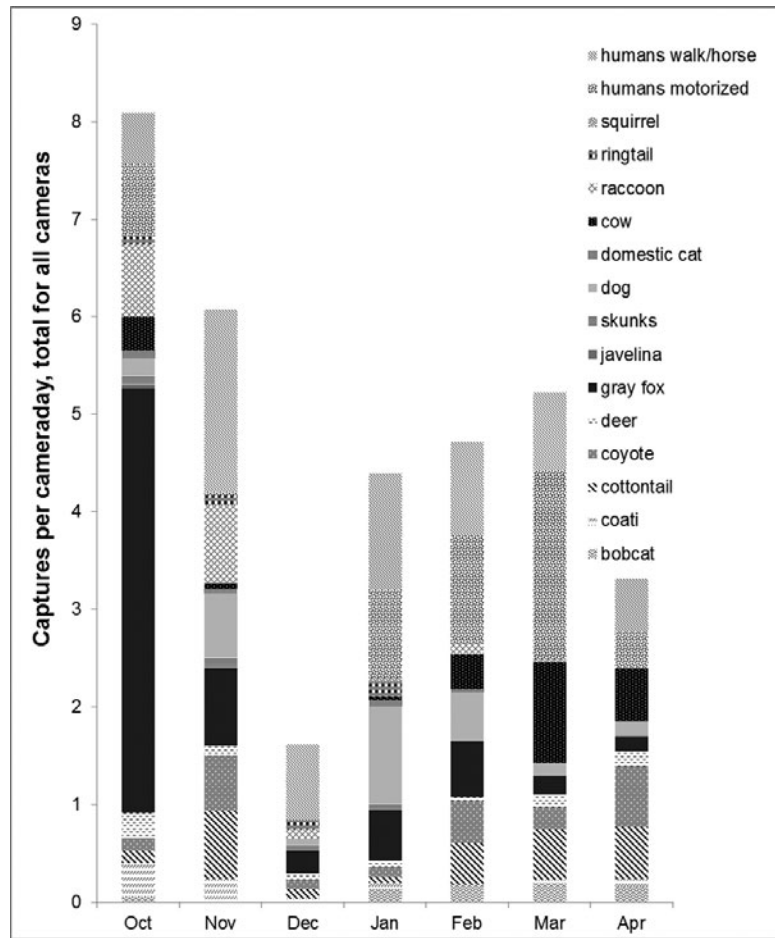


Figure 5—Sittings per camera-day, grouped by month, Greater Oak Flat Watershed near Superior, Arizona.

to differentiate whether we are observing a hiker or a rock climber by the gear that is carried. We have several observations of domestic cats (*Felis catus*) that appear to have gone feral, but observations of domestic dogs (*Canis familiaris*) show that all have been paired with humans. Locations with domestic cats were those closest to paved roads and permanent human activity. Records and analysis of human activities hopefully will not only allow us to determine whether wild species are being displaced, but will also create a useful record for land managers to provide ongoing recreational opportunities on public land.

The data so far show a broad distribution of herbivores and mesocarnivores, but to date is lacking records of large carnivores such as black bear (*Ursus americanus*) and mountain lion (*Puma concolor*). Previous wildlife surveys have indicated that black bear occur in the study area (Jacobs and Flesch 2007) and there appears to be suitable, if not ideal, habitat for mountain lions. Possible reasons for this may include insufficient time to capture images of less abundant species or that they have been displaced by increasing human activities such as those associated with drill rigs and industrial mining activities. While recreation has been ongoing for generations in the study area (Roy Chavez, personal communication), additional human activities such as those associated with drill rigs and other mining equipment have not.

Conclusions

The period of this survey to date has been the year’s cooler months (October through April). We expect human recreational activity to be higher in the cooler months and to drop off over hotter summer months. This project has been recording data for a relatively short time frame of 6 months. Over the course of the study, which is planned to be 2 years or longer, clearer trends and usage patterns should develop. In addition, a full year of data should solidify seasonal trends.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.



Posters

Medium and Large Mammals in the Sierra La Madera, Sonora, Mexico

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Reserva Forestal Nacional y Refugio de Fauna Silvestre Ajos-Bavispe, Cananea, Sonora

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Abstract—Sierra La Madera is a Sky Island mountain range in the Madrean Archipelago. It is in Fracción V of the Ajos-Bavispe CONANP Reserve in the Municipios (= Counties) of Cumpas, Granados, Huásabas, Moctezuma, and Villa Hidalgo. Medium and large mammals were inventoried using camera traps. Eighteen Wild View 2[®] camera traps were deployed during four sampling periods: August–September, September–November, and November–December (two times). The first and second sampling periods were on Ranchos La Bellota, La Palmita, and San Fernando in the southern Sierra La Madera. The last two sampling periods were on Ranchos La Mesa and El Mezquite, and Brecha CONAFOR in the northern Sierra la Madera, and again Brecha CONAFOR. The vegetation sampled was foothills thornscrub, oak woodland and pine-oak forest. Eighteen species of mammals in the orders Carnivora, Artiodactyla, Didelphimorphia, Lagomorpha, and Rodentia were photographed. Four species of birds, including *Aquila chrysaetos* (golden eagle) were also photographed.

Introduction

Sierra La Madera is a Sky Island mountain range located in the transition between the New World tropics and the northern temperate zone that is about 29°N in east-central Sonora, which enhances the diversity of flora and fauna. There are very few faunal studies of any kind in the Sky Island Region in Sonora. In 2011, Universidad de la Sierra together with the CONANP Ajos-Bavispe Reserve began faunal inventories using camera traps in the Sierra La Madera. Here, we present the preliminary documentation of medium and large mammals from 2011–2012.

Study Area

The Ajos-Bavispe National Forest Reserve and National Wildlife Refuge is a Reserve in the Comisión de Áreas Protegidas Naturales (CONANP) system in northeastern Sonora, Mexico. It covers most of 184,000 hectares in five areas. Fracción I is in Sierra Pilares de Teras and part of the Sierra del Tigre. Fracción II is in the Sierra Pilares de Nacozari. Fracción III is in San Diego and part of the Sierra del Tigre. Fracción IV includes the Sierras de Ajos, Buenos Aires, and La

Púrica. Fracción V includes the Sierra La Madera at 29°55'N latitude 109°30'W longitude (fig. 1). Complex topography and an elevational range of ca. 1685 m (from 615 m along Río Bavispe at Huásabas to over 2300 m on the highest peak) result in diverse habitats. The Sierra la Madera is in the Municipios of Cumpas, Granados, Huásabas, Montezuma, and Villa Hidalgo, Sonora. Vegetation in the Sierra la Madera along an elevational gradient is foothills thornscrub, desert grassland, oak woodland, and pine-oak and pine forests (INEGI, 1980; Yanes-A. and others 2010).

According to Caire (1978) and other references cited in CONANP (s/f), the potential mammal fauna in the Ajos-Bavispe Reserve is 93 species, representing 62.4% of the mammals of Sonora (Castillo-Gómez and others 2010) including white-tailed deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), puma (*Puma concolor*), collared peccary (*Tayassu tajacu*), gray fox (*Urocyon cinereoargenteus*), squirrels (*Sciurus arizonensis*, *Spermophilus variegatus*), rabbits (*Lepus* spp., *Sylvilagus* spp), and others.

Materials and Methods

Wildview Extreme 2[®] Camera traps were placed in habitats during four periods from August 2011 to January 2012. They were strategically located at approximately 1 kilometer intervals on tree trunks 30 and 70 cm above the ground, with a north-south orientation. Attractants (canned sardines or corn moistened with vanilla extract) were placed at a distance of about 3 m from the cameras. Geographical coordinates and elevations were obtained using a Garmin Etrex Garmin[®] GPS unit. Dominant plant species were listed to describe the habitat at each site.

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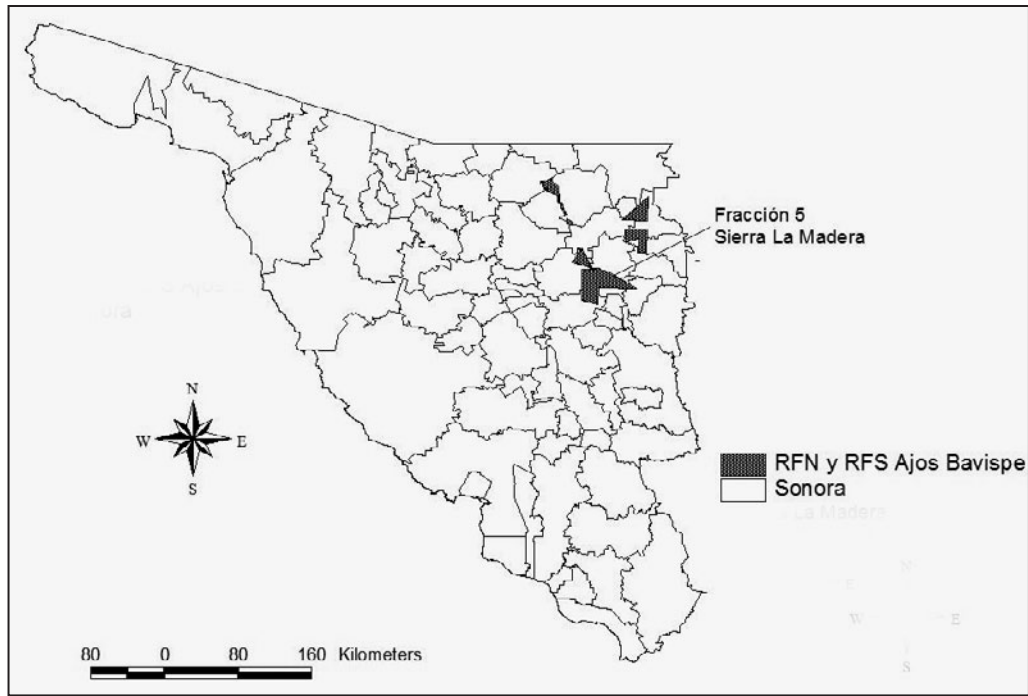


Figure 1—Study area, Ajos-Bavispe National Forest Reserve and national wildlife Refuge in northeastern Sonora. Fracción V includes the Sierra La Madera at 29°55'N latitude 109°30'W longitude.

Table 1—Wildlife species recorded in August-December 2011 by camera traps in the Sierra La Madera, Montezuma, Sonora. SP = sampling period. *Species with protection category according to NOM-059-SEMARNAT-2010.

Order	Family	Species	SP 1	SP 2	SP 3	SP 4
Carnívora	Canidae	<i>Urocyon cinereoargenteus</i>	X	X	X	X
		<i>Canis latrans</i>	X	X	X	
	Felidae	<i>Puma concolor</i>	X	X	X	X
		<i>Leopardus pardalis</i> *			X	X
		<i>lynx rufus</i>	X	X	X	X
	Ursidae	<i>Ursus americanus</i> *		X		
	Mephitidae	<i>Mephitis macroura</i>	X	X	X	
		<i>Conepatus mesoleucus</i>	X	X	X	X
		<i>Spilogale putorius</i>	X	X	X	X
	Procyonidae	<i>Nasua narica</i>	X	X	X	
<i>Bassariscus astutus</i>			X	X		
<i>Procyon lotor</i>				X		
Artiodactyla	Cervidae	<i>Odocoileus virginianus</i>	X	X	X	X
	Tayassuidae	<i>Tayassu tajacu</i>	X	X	X	
Didelphimorphia	Didelphidae	<i>Didelphis virginiana</i>		X	X	
Lagomorpha	Leporidae	<i>Sylvilagus floridanus</i>		X		X
Rodentia	Sciuridae	<i>Sciurus arizonensis</i>			X	X
Rodentia	Sciuridae	<i>Spermophilus variegatus</i>	X	X	X	X

The first and second sampling periods were on Ranchos La Bellota, La Palmita/Mesa Quemada, and San Fernando in the southern Sierra la Madera. The third sampling period was on Ranchos El Mesquite and La Mesa, and on Brecha CONAFOR. During the fourth sampling period, six cameras were returned to Brecha CONAFOR.

Results

Eighteen species of mammals were recorded in orders Carnivora (five families), Artiodactyla (two families), Rodentia, Lagomorpha, and Didelphimorphia (one family each). Of mammals photographed, 55% were medium-sized mammals and 45% large mammals (table 1). Domestic or wildlife species introduced by man were also documented, including cows, horses, burros, goats, and dogs. Fourteen mammal

species were photographed during the second sampling period. A single black bear (*Ursus americanus*) was seen at Rancho San Fernando

Discussion and Conclusions

Fifty-five percent of the records belong to medium-sized mammals. The rock squirrel (*Spermophilus variegatus*) was the most abundant species. In the large mammals, the white-tailed deer was the most abundant. Medium-sized mammals were most common in fall-winter, while large mammals were seen more often in summer-fall.

The Sierra La Madera mammal fauna has only 19.4% of the 93 mammal species potentially occurring in the Ajos-Bavispe Reserve (Caire, 1978; CONANP, s / f), but small species were not sampled.

The Arizona gray squirrel (*Sciurus arizonensis*) was seen in the third and fourth sampling periods in oak woodland and pine-oak forest on Rancho la Mesa and Brecha CONAFOR. This is a 110 east-southeast range extension from Arroyo Santo Domingo near Cucurpe of a central Arizona-northern Sonora regional endemic species. The Mexican Fox Squirrel (*Sciurus nayaritensis*) was not photographed in the present study, but was previously observed on Rancho San Fernando by Stephen L. Minter in August 2010 and the northern Sierra La Madera by Dale Turner in September 2003 (see Madrean Archipelago Biodiversity Assessment [MABA] database, Madrean.org). This is a Sierra Madre Occidental species reaching its western range limits.

Three species of mammals (*Leopardus pardalis*, *Sciurus arizonensis*, *U. americanus*) as well as golden eagle (*Aquila chrysaetos*) are protected under NOM-059-SEMARNAT-2010. These results are

preliminary and additional camera traps in different areas and habitats are needed to more fully document the mammal fauna of the Sierra La Madera, which likely contains jaguar (*Panthera onca*).

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Herpetofauna at the Appleton-Whittell Research Ranch

Roger C. Cogan

Appleton-Whittell Research Ranch of the National Audubon Society, Elgin, Arizona

Abstract—A rich diversity of amphibian and reptile species occurs at the Appleton-Whittell Research Ranch, an 8000-acre sanctuary for native biota and research facility in the semi-arid grasslands of southeastern Arizona, created in 1969 and managed by the National Audubon Society since 1980. Nine species of amphibians and 42 species of reptiles have been identified by staff and researchers within the preserve. Efforts are underway to document the current richness of the herpetofauna. Recent surveys in 2010–2012 have confirmed continued presence of 26 species. As part of that inventory effort, we located seven overwintering sites of rattlesnakes. Our challenge into the future is to adaptively manage the Research Ranch to provide sanctuary to the appropriate plant and animal species under a likely changing climate.

Introduction

Since cattle were removed in the 1960s collecting efforts over several decades by numerous researchers have identified 9 amphibian and 42 reptile species representing 29 genera within the preserve. There have been ongoing investigations with several individual species. However, the herpetofauna as a whole has not been assessed. Efforts are currently ongoing to locate and document the continued existence or absence of all herp species that occur within the Research Ranch boundaries and to discover and track use of wintering sites used by rattlesnakes.

Methods and Results

The Research Ranch management area covering 8000 acres is primarily semi-arid grassland. Partners include the Bureau of Land Management, U.S. Forest Service, Resolution Copper Company, The Research Ranch Foundation, and The Nature Conservancy. In addition to its own property, Audubon manages parcels of land owned by these partners under various contractual agreements. Conservation and research are key elements of management agreements.

Searches for amphibians and reptiles are conducted when conditions are appropriate for herp surface activity; however, most encounters occur during times when staff and researchers are traveling or working in the field. When sightings occur, they are documented with photographs whenever possible and recorded. Unique and rare sightings are recorded with GPS for future reference.

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Conclusions

During the history of the Research Ranch there have been several surveys for herps and individual species have been investigated (*i.e.* Dodero and Spengler, unpublished checklist; Smith and Chiszar 2002). This is the first attempt to monitor and document presence or absence of all herp species previously identified at the sanctuary. Since 2010 surveys have confirmed that 26 species are still present at the Research Ranch (table 1). Seven rattlesnake wintering sites have thus far been identified and located. These locations are primarily located adjacent to wash drainages in rock outcrops or boulder piles. They are occupied by Western Diamondback Rattlesnakes (*Crotalus atrox*) (fig. 1) and Black-tailed Rattlesnakes (*Crotalus molossus*). These sites are also utilized by Sonoran Gopher snake (*Pituophis catenifer affinis*) and Sonoran Whipsnake (*Masticophis bilineatus*). Rock rattlesnake (*Crotalus lepidus*) and Mohave rattlesnake (*Crotalus scutulatus*) wintering sites currently have not been located. Efforts are underway to locate other preferred wintering sites.

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Table 1—Herpetofauna identified at the Research Ranch.

Amphibians: Nine species, of seven genera

Red-spotted Toad ^a	(<i>Anaxyrus punctatus</i>)
Sonoran Desert Toad ^a	(<i>Ollotis alvarius</i>)
Couch's Spadefoot Toad	(<i>Scaphiopus couchii</i>)
Chihuahua Spadefoot Toad ^a	(<i>Spea multiplicata stagnalis</i>)
Canyon Treefrog ^a	(<i>Hyla arenicolor</i>)
Tiger Salamander	(<i>Ambystoma mavortium ssp.</i>)
Chiricahua Leopard Frog	<i>Lithobates chiricahuensis</i> Believed to be extirpated
Lowland Leopard Frog	(<i>Lithobates yavapaiensis</i>) Believed to be extirpated
American Bullfrog ^a	(<i>Lithobates catesbeiana</i>) Invasive non-native

Lizards: Nineteen species, of eight genera

Arizona Striped Whiptail	(<i>Aspidoscelis arizonae</i>)
Canyon Spotted Whiptail	(<i>Aspidoscelis burti stictogrammus</i>)
Chihuahuan Spotted Whiptail	(<i>Aspidoscelis exsanguis</i>)
Gila Spotted Whiptail	(<i>Aspidoscelis flagellicaudus</i>)
Sonoran Spotted Whiptail ^a	(<i>Aspidoscelis sonorae</i>)
Sonoran Tiger Whiptail	(<i>Aspidoscelis tigris punctilineatus</i>)
Desert Grassland Whiptail ^a	(<i>Aspidoscelis uniparens</i>)
Eastern Collared Lizard	(<i>Crotaphytus collaris</i>)
Madrean Alligator Lizard ^a	(<i>Elgaria kingii nobilis</i>)
Mountain Skink	(<i>Plestiodon callicephalus</i>)
Great Plains Skink	(<i>Plestiodon obsoletus</i>)
Chihuahuan Earless Lizard ^a	(<i>Holbrookia maculata flavilenta</i>)
Greater Short-horned Lizard ^a	(<i>Phrynosoma hernandesi</i>)
Round-tailed Horned Lizard	(<i>Phrynosoma modestum</i>)
Regal Horned Lizard	(<i>Phrynosoma solare</i>)
Clark's Spiny Lizard ^a	(<i>Sceloporus clarkii</i>)
Slevin's Bunchgrass Lizard ^a	(<i>Sceloporus slevini</i>)
Southwestern Fence Lizard ^a	(<i>Sceloporus cowlesi</i>)
Ornate Tree Lizard ^a	(<i>Urosaurus ornatus linearis</i>)

Snakes: Twenty species, of twelve genera

Western Diamondback Rattlesnake ^a	(<i>Crotalus atrox</i>)
Mojave Rattlesnake ^a	(<i>Crotalus scutulatus</i>)
Rock Rattlesnake ^a	(<i>Crotalus lepidus</i>)

Black-tailed Rattlesnake ^a	(<i>Crotalus molossus</i>)
Regal Ringneck Snake ^a	(<i>Diadophis punctatus regalis</i>)
Chihuahuan Hook-nosed Snake	(<i>Gyalopion canum</i>)
Mexican Hognose Snake	(<i>Heterodon nasicus kennerlyi</i>)
Spotted Nightsnake	(<i>Hypsiglena torquata ochrorhynchus</i>)
Western Black Kingsnake	(<i>Lampropeltis getula nigrata</i>)
Desert King Snake	(<i>Lampropeltis g. splendida</i>)
Arizona Mountain Kingsnake ^a	(<i>Lampropeltis p. pyromelana</i>)
Sonoran Whipsnake ^a	(<i>Masticophis bilineatus</i>)
Sonoran Coachwhip	(<i>Masticophis flagellum cingulum</i>)
Sonoran Coral Snake	(<i>Micruroides e. euryxanthus</i>)
Sonoran Gopher Snake ^a	(<i>Pituophis catenifer affinis</i>)
Western Patchnose Snake	(<i>Salvadora deserticola</i>)
Eastern Patchnose Snake ^a	(<i>Salvadora g. grahamiae</i>)
Western Groundsnake ^a	(<i>Sonora semiannulata</i>)
Western Black-necked Garter Snake ^a	(<i>Thamnophis c. cyrtopsis</i>)
Mexican Garter Snake	(<i>Thamnophis eques megalops</i>)
Checkered Garter Snake ^a	(<i>Thamnophis m. marcianus</i>)

Turtles: Two species, of two genera

Sonoran Mud Turtle ^a	(<i>Kinosternon sonoriense</i>)
Desert Box Turtle ^a	(<i>Terrapene ornate luteola</i>)

^aContinued presence visually observed and documented with photographs 2010-2012.



Figure 1—Western Diamondback Rattlesnake (*Crotalus atrox*).

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Late Quaternary Brown Bear (Ursidae: *Ursus* cf. *arctos*) From a Cave in the Huachuca Mountains, Arizona

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Abstract—In 2008, Steve Willsey discovered the fragmentary cranium of a bear loose on the floor of a cave at about 2270 m elevation near the crest of the Huachuca Mountains. In 2009, we revisited the cave to examine the specimen with the intention of identifying the species. We photographed and measured the main pieces and left them in the cave. The skull is from an adult, probably male, with prominent sagittal crest. Bears are highly variable morphologically and their remains are difficult to identify. The morphological features and measurements of the Huachuca Mountains cranium are somewhat equivocal, but most available features indicate a brown bear, *Ursus* cf. *arctos*. Some parts are encrusted with carbonate and could be better examined after collection and preparation as well as comparison with late Pleistocene brown and black bears. Based on its state of preservation, the cranium possibly represents a late Pleistocene occurrence, which could be determined by radiometric dating. There is no previous fossil record of *U. arctos* in the Sky Islands, nor in the rest of Arizona, New Mexico, Chihuahua, or Sonora. Despite the lack of other fossil records in the region, this late Quaternary occurrence affirms the historic records of the species in the Apache Highlands before extirpation.

Introduction

As with the dynamics of diverse indigenous cultures of Apacheria before colonization, an understanding of the present-day biodiversity of the Apache Highlands region can benefit from the temporal perspective of recent geological time (Martin 2005). The Quaternary fossil record may also inform certain management decisions. Historically, grizzly (brown) bears occurred throughout the Sky Islands region and beyond (see map of historic records in Brown, 1985:42-43; also in Brown and Davis 1995; Cortés-Calva 2000; Pavlik 2006). Most grizzly bears were killed out during the second half of the nineteenth century, with few surviving in the Southwest until the mid-twentieth century. The latest historical record in southwestern North America was about 1976 in northern Sonora (Gallo-Reynoso and others 2008). Black bears are known widely throughout Apacheria from late Pleistocene to the present day. We report an as-yet undated Quaternary occurrence of a probable brown bear, *Ursus* cf. *U. arctos*, in a high-elevation cave in the Huachuca Mountains, Cochise County, Arizona.

Materials and Methods

Steve Willsey discovered the fragmentary cranium of a bear loose on the floor of a cave at about 2270 m elevation near the crest of the

Huachuca Mountains, Arizona, in 2008. We revisited the cave in 2009 to examine the specimen with the intention of identifying the species. We photographed and measured the main pieces and left them in the cave. The skull has a prominent sagittal crest indicating an adult, probably male individual. Some parts are encrusted with carbonate and could be better examined after collection and preparation as well as direct comparison with late Pleistocene brown and black bears. Bears are highly variable morphologically and their remains are difficult to identify. In parts of North America, many black bears (*Ursus americanus*) were larger in the late Pleistocene and underwent a size reduction in the Holocene, further complicating the identification of fossil bears.

The cranium is broken into several pieces (fig. 1). The braincase is mostly intact and forms the largest piece with the ethmoid plate preserved anteriorly. Both zygomatic arches are broken away at their bases, the left mastoid, petrosal, and occipital condyle are missing. The sagittal crest is long, tall, and strong. A fragment of the right frontal bone includes the postorbital process. The right maxilla-premaxilla is broken into two pieces and includes the anterior root of the zygomatic arch. Several small pieces also are present. Teeth I1 and I2 are not preserved, while I3 and C1 are broken off at the alveolar rims but the root of each is present. Crowns of P4, M1, and M2 are present. Posterior to the canine, the maxilla and cheek teeth are encrusted with carbonate; however, at least two empty alveoli for small premolars are present, one posterior to C1 and one anterior to P4. P4 is encrusted with carbonate but appears to have a well-developed median accessory cusp. M2 is broadest anteriorly rather than at its midpoint.

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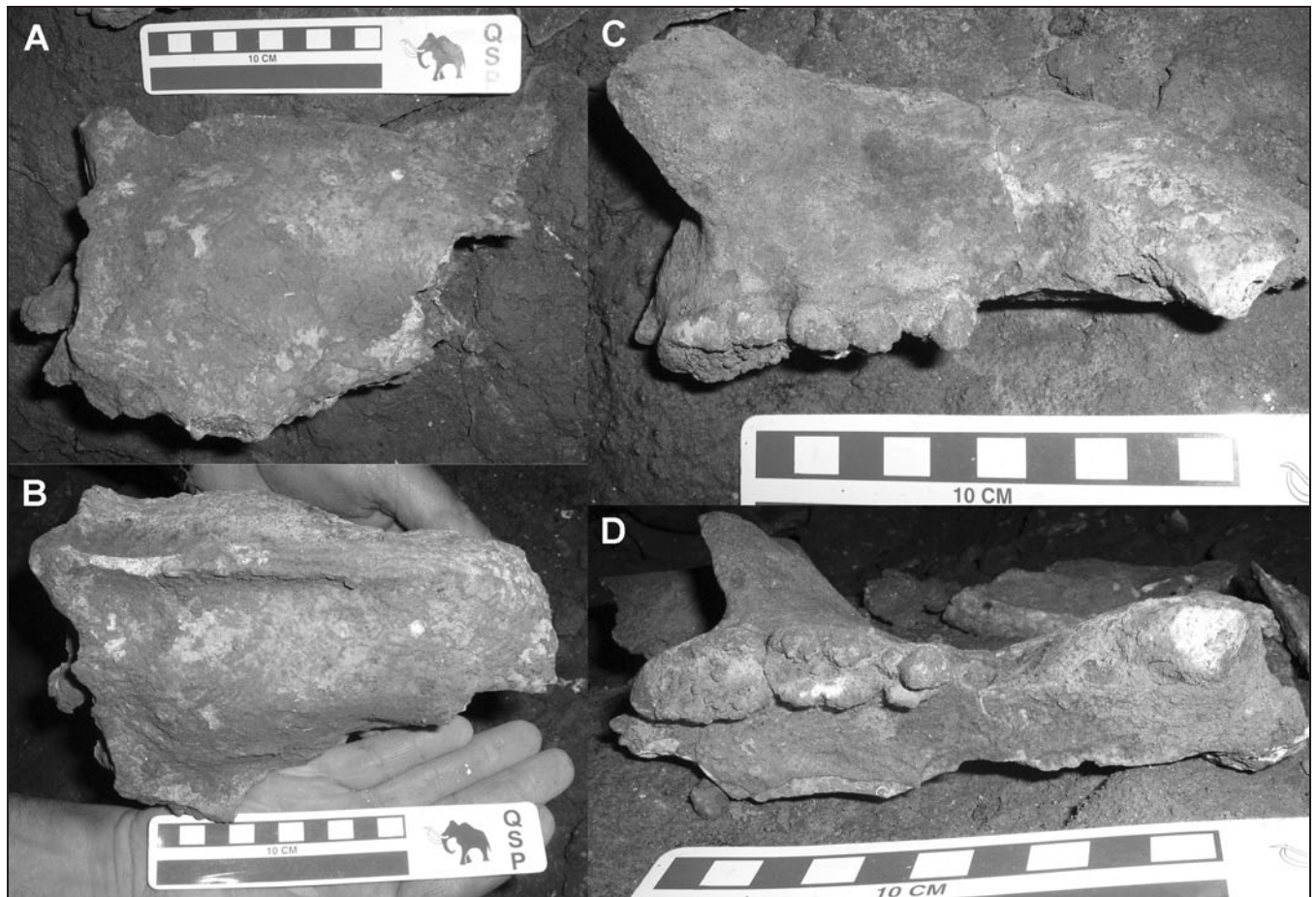


Figure 1—Portions of a Quaternary bear cranium from a cave in the Huachuca Mountains, Arizona. A-B, braincase in right lateral (A) and dorsal (B) views. C-D, right half of rostrum with parts of the jugal, palatine, premaxillary, and maxillary including the root of the upper canine, alveoli for small premolars, and intact P4-M1-M2, in lateral (C) and palatal (D) views. Much of the teeth and bone surface is encrusted with carbonate.

Results and Discussion

Qualitative morphological characteristics of the cranium and teeth distinguish the Huachuca Mountains cranium as a member of the sub-family Ursinae (brown and black bears) rather than the Tremarctinae (short-faced and spectacled bears), which are also known as fossils in the Pleistocene and Pliocene epochs in the Sky Island region. Measurements of the cranium are provided in table 1. By comparison with recent brown and black bears from the Southwest (Hoffmeister 1986), the cave fossil shows similarities with both brown and black bears. In two qualitative characters the fossil matches brown bears: the median accessory cusp on P4 is normally present in brown bears *Ursus arctos* and normally absent in black bears, *Ursus americanus*; and the M2 being broadest anteriorly characterizes brown bears, whereas in black bears M2 is broadest at the midpoint. M1 dimensions of the fossil are consistent with grizzly bears in quantitative mensural characters that have been used previously to distinguish the two species (table 1), whereas M2 dimensions are larger than or consistent with the largest recent black bears (Miller and others 2009) but near the average for Sonoran brown bears. Gordon (1977) suggested that the M1 is greater than 20.4 mm long and 10.5 mm wide in grizzly bears and less in black bears; the Huachuca Mountains bear's M1 is 20.8 x 15.6 mm. The Huachuca Mountains bear's cranium is also larger in the few available comparative measurements than a late Pleistocene

fossil black bear from Papago Springs Cave, Canelo Hills, Arizona (Skinner 1942). The morphological features and measurements of the Huachuca Mountains cranium are somewhat equivocal but most available features indicate a brown bear, *Ursus cf. arctos*. Based on its state of preservation, the cranium possibly represents a late Pleistocene occurrence, which could be determined by radiometric dating. There is no previous fossil record of *U. arctos* in the Sky Islands, nor in the rest of Arizona, New Mexico, Chihuahua, or Sonora. If the fossil is collected, it could be cleaned of carbonate and repaired. It could then be compared with recent specimens from southwestern North America of black and brown bears, and also with late Pleistocene black bears with a view toward further discriminating the species.

The Huachuca Mountains fossil is important because it provides the first late Pleistocene fossil record of a probable brown bear in Apacheria and in all of Arizona, New Mexico, Chihuahua, and Sonora (Arroyo-Cabrales and others 2002; Harris 1993, 2005, 2012; Mead and others 2005; Morgan and Lucas 2005; White and others 2010). Although they might not have been continuously contemporaneous in the region, this record indicates that three bears, *U. cf. arctos*, *U. americanus*, and *Arctodus simus* (giant short-faced bear; Czaplewski unpublished data) occurred in the Madrean Archipelago in the late Pleistocene. Stable isotope analyses indicate that short-faced bears were highly carnivorous and possibly specialized as scavengers compared to brown bears (Matheus 1995). Perhaps the presence of

Table 1—Measurements (in mm) of intact portions of the Huachuca Mountains, Arizona, fossil bear cranium compared with some of the same measurements published for recent bears in the Sky Islands region.

Element measured	Huachuca Mts. <i>Ursus</i> cranium	<i>Ursus arctos</i> SON ^a	<i>Ursus arctos</i> CHI ^b	<i>Ursus arctos</i> AZ, NM ^c	<i>Ursus americanus</i> AZ, NM ^d
Foramen magnum diameter	[35] ^e				
Breadth across occipital condyles	[71]				
Braincase breadth	109.3	89	96.7 (95-98)		
Maxillary toothrow length	119.7				
C1 length	22.0				
C1 width	15.6				
P4-M2 length	63.5	56		74.07 (67.2-80.0)	53.07 (50.1-57.6)
P4 length	13.5	19.2	21.7 (20.9-21.9)		
P4 width	11.4				
M1 length	20.8				
M1 width	15.6				
M2 length	29.1	26.8		36.09 (33.1-39.9)	25.31 (22.7-28.6)
M2 width	16.6	15.4		19.62 (18.2-20.5)	15.08 (13.8-16.0)

^aOne *U. arctos* of unknown sex from Sonora (SON) provided by Gallo-Reynoso et al. (2008).

^bMean and observed range of 3 male *U. arctos* from Chihuahua (CHI) provided by Anderson (1972).

^cMean and range of 10 male *Ursus arctos* from Arizona (AZ) and New Mexico (NM) provided by Hoffmeister (1986:tables 5.72, 5.73).

^dMean and range of 8 male *Ursus americanus* from Arizona and New Mexico (Hoffmeister 1986:tables 5.72, 5.73).

^eBrackets [] indicate estimated measurement of broken element.

the carnivorous short-faced bear constrained the body size of grizzly bears in the Pleistocene.

Pavlik (2006) reviewed late Pleistocene records of black bears in the Huachuca Mountains and Sky Islands as well as many other aspects of their biology and conservation. He noted that black bears still occur in the Huachuca Mountains in modest numbers amid increasing pressure from human encroachment, habitat loss, and recent drought and fire. Although undated, the occurrence of a brown bear in the Huachuca Mountains at some time during the late Quaternary affirms the historic records of the species in the Apache Highlands before it was eradicated and lends support to estimates of the suitability of still-existing habitat there for the species (Povilitis 1995). We must adopt a cultural ecological moral to share this region with the bears and other living things, understand that they and we are integrative forces in the region, and pass on the same responsibilities to our children in the greater scheme of conserving bears across the region.

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FireScape: A Program for Whole-Mountain Fire Management in the Sky Island Region

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***Abstract**—The Coronado National Forest’s (CNF) FireScape program works to remove barriers to fire playing its natural role on the landscape. A long-term goal is creating landscapes that are able to survive wildfire with biodiversity and key ecological processes intact, especially important in the face of a drier, hotter Southwest. The FireScape team is nurturing multiple efforts around the Sky Islands—no two projects are alike, but those underway share an approach that includes multiple jurisdictions, investigations by University of Arizona scientists, public engagement, assessing treatment need at the whole-mountain scale, and creatively removing implementation barriers when funding is scarce. Clearance for treatments in designated Wilderness is a need across all projects. The FireScape team has completed a fuels map and an analysis of departure from reference condition for southeastern Arizona that covers the CNF and partner lands. Partners have worked together to update Landfire data for this 14 million-acre area. These products provide inputs for fire behavior and effects analyses to support decision making and outreach. The website www.azfirescape.org is a work in progress that displays project information, including maps, reports, and vegetation and fuels data*

“FireScape” is a Coronado National Forest (CNF) program for expanding safe, ecologically sound, large-scale, multi-party fire management across southeastern Arizona. The leadership team consists of representatives from the Forest Service, The Nature Conservancy, the University of Arizona (UA), and other regional land managers. This paper represents a 2012 progress report for work that has been underway for more than 10 years and that needs to remain a priority for land managers in the region. The 2011 fire season in the Southwest brought a 300% increase in area burned compared with the average for the previous 10 years—2.20 million acres (vs. 0.67 million) in Arizona, New Mexico, and West Texas (NIFC 2011). High-severity effects in dry woodland and forest types have left land managers uncertain about recovery trajectories (Wallow Fire example, Wadleigh 2011).

The CNF covers a number of dispersed mountain ranges separated by non-Forest Service land. These Sky Islands present different physical and biological backgrounds and challenges as well as different sets of neighbors. Thus they require custom approaches to fire management. Commercial timber operations have limited feasibility on this

landscape, which makes it difficult to compete for treatment funding that ranks “utilization” significantly. The mountains and valleys of southeastern Arizona, however, have tremendous value as watersheds, habitat, working lands, and recreation sites. The importance of the FireScape project is magnified given the 2011 fires.

The many goals of FireScape can be condensed into a creative approach to fire management at a much bigger scale than in the past. The grasslands, woodlands, and forests of southeastern Arizona evolved under regimes of frequent low- and mixed-severity fire—on the order of every 5 to 20 years (Kaib 1998, Swetnam and Baisan 1996). If 1.5 million acres of the CNF used to burn every 15 years, keeping up means treating 100,000 acres/year. In some (but not all) years the Forest might come close to half or two-thirds that acreage. Expanding treatment and getting ahead of high-severity wildfires not only reduces the loss of healthy systems but also costs less than wildfire suppression and generates less smoke.

A long-term goal is creating landscapes that are able to survive wildfire with biodiversity intact, which becomes especially important in the face of a drier, hotter Southwest. Projects include monitoring that assesses our success and guides adjustments to improve our management. This work comes at a time when the CNF is also managing more wildfires for resource benefit, a shift from reliance on prescribed fire and other planned treatments to keep landscapes healthy. FireScape also emphasizes the need to keep fire out of systems where frequent fire has not been the norm, such as upland Sonoran desert, Arizona chaparral, and mountaintop spruce-fir systems.

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The FireScope program is one facet of the CNF's work underway for more than a decade to remove barriers to fire playing its natural role on the landscape. Other efforts include the Peloncillo Programmatic Fire Plan (1999) that laid out procedures for carrying out large-scale burns in the Peloncillo Mountains while protecting the endangered New Mexico ridge-nosed rattlesnake. The Pinaleno Ecosystem Restoration Program (2011) specifies careful mountaintop treatments that will protect sensitive resources and safely allow fire to play a natural role elsewhere in the range. The CNF is also a party to the Altar Valley Fire Management Plan (2008) that proposes to restore grasslands along and adjacent to the forest's southwestern edge.

The FireScope team is currently nurturing efforts at four locations around the Coronado—no two projects are alike, but those underway share an approach that includes multiple jurisdictions, UA scientists at the table, assessing treatment need at the whole-mountain scale, and completing compliance at large scale and across programs (NEPA, Endangered Species Act section 7, and cultural resources). Getting clearance from the Regional Forester for treatments in designated Forest Service Wilderness is a need across all FireScope projects. We have completed a fuels map and “departure” analysis for southeastern Arizona that covers the CNF and partner lands. Partners worked together to correct and update Landfire data for a 14 million-acre area. These products provide inputs for fire behavior and effects models to support decision making and outreach.

In 2009, the Huachuca FireScope project completed a three-agency Environmental Assessment (National Environmental Policy Act [NEPA] compliance) and received a Biological Opinion (Endangered Species Act compliance) covering a menu of treatments for 400,000 acres in southeastern Arizona. Coronado National Memorial (National Park Service), and Fort Huachuca (U.S. Army) are the other federal partners, but adjacent Bureau of Land Management (BLM), TNC, Audubon, and private ranch lands are included in the greater planning area. These partners have worked together for over a decade to coordinate fire management in an area where wildfires burn freely across boundaries. Key treatments are large prescribed burns, but also thinning the growing wildland-urban interface (WUI). The compliance phase was completed with no appeals, and fire staff are implementing projects as funding becomes available. The 2011 Monument Fire burned 30,000 acres of the Huachuca landscape.

The 500,000-acre Catalina-Rincon FireScope includes UA research aimed at predicting fire behavior on landscapes that are topographically and ecologically complex, contain a mixture of vegetation types, and have recently experienced uncharacteristically severe wildfires. The project highlights differences in how fire has shaped the Santa Catalina versus the Rincon mountains, which share similar physical and biological conditions, but different land use histories. Ecological mapping was completed in 2009 and covers partner lands—CNF, NPS, State of Arizona, and private. Treating in designated Wilderness is a challenge for this landscape but is needed to preserve desired ecological conditions, improve wildlife management opportunities (particularly desert bighorn sheep), make prescribed fire more feasible, and reduce threats to WUI. Public engagement is a huge component, given the Tucson's-backyard location. Formal compliance (NEPA, ESA section 7, NHPA) is underway; public scoping for NEPA took place during spring 2011. Catalina-Rincon work also analyzes carbon cycle effects of fire treatments and coordinates with efforts to halt the spread of invasive buffelgrass, a species that introduces fire into non-fire-adapted upland Sonoran desert.

The Chiricahua FireScope focuses on restoring natural fire regimes in the Chiricahua, Dragoon, and Dos Cabezas mountains, plus adjacent lands. Chiricahua National Monument and Fort Bowie National Historic Site are National Park Service partners, and the BLM, USFWS Leslie Canyon National Wildlife Refuge, the State of Arizona, and Natural Resources Conservation Service have also joined the planning. A number of grazing permittees who own lands adjacent to agency holdings have elected to participate. Total acreage for this project is running at about 500,000. Ecological mapping across jurisdictions has been completed, and the new fuels layer and departure analysis allow modeling fire behavior and effects with and without treatments. The science component includes a synthesis of and addition to fire history work for these mountains. Public scoping for NEPA occurred in early 2011. The 2011 Horseshoe 2 Fire burned throughout the Chiricahua range, but its effect on the project is reassessment rather than postponement.

The 135,000-acre Galiuro FireScope covers remote country with little WUI and concentrates on very large-scale burns. We are making a case on this landscape to use helicopter ignition for prescribed burning in designated Wilderness. The CNF, BLM, TNC, UA, and grazing permittees are project parties. Additional fire history studies are incorporated into the science side of this project. Compliance is underway, and a 40,000-acre three-party (BLM, TNC, CNF) burn is in the works.

Cross-boundary, large-scale fire management comes with numerous institutional challenges. All-lands conservation is a directive to agencies that have few resources to devote to such work. Agency turnover means passion ebbs and flows—loss of key players slows the process way down. FireScope competes with other agency programs for staff attention while wildfires get bigger and display increasingly severe effects. Funding for planning and implementation is not likely to increase soon. The FireScope teams carry on, knowing that the work is needed, and that creative, broad-based efforts ultimately succeed. The website www.azfirescape.org is a work in progress that displays project information, including maps, for FireScope.

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Floristic Analysis of Heterogeneous Landscape Patches in a Biological Corridor in the El Rodeo-Básora Area near Moctezuma, Sonora, Mexico

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Abstract—A floristic study was conducted in a heterogeneous landscape near Moctezuma, Sonora. From August to December 2011, Ranchos El Rodeo and El Básora were visited three times. The vegetation at about 900 m elevation is foothills thornscrub, oak woodland, and induced buffelgrass grassland. A total of 120 plant taxa in 95 genera and 41 families were documented. Taxa were identified using regional literature, consulting with experts, and comparison with specimens in the Universidad de Sonora Herbarium. The families with more taxa are Asteraceae, Convolvulaceae, Fabaceae, and Solanaceae. The study area is a transitional zone between thornscrub oak woodland, making it an important biological corridor in central Sonora. Loss of flora is due to land use practices, especially clearing to introduce grass like buffelgrass (*Pennisetum ciliare*). Non-native plants could displace native taxa like *Zinnia zinnoides*, *Ipomoea cristulata*, and *I. hederacea*.

Introduction

The floristic richness of east-central Sonora is due to its location in the transition between the New World tropics and the northern temperate zone at about 29°N, which enhances the diversity of flora, fauna, vegetation types, and habitats. Large geographic areas with difficult access have not been explored botanically. This paper documents the flora and characterizes plant community patches in a heterogeneous landscape in this area (Wiens 1995), which could be used as biological corridors between foothills thornscrub, desert grassland, and oak woodland. Our floristic inventory in Ranchos El Rodeo-Básora area in the Municipio de Moctezuma is an important contribution to the flora of Sonora.

Study Area

The Ranchos El Rodeo-Básora area is a corridor that connects the mountains of central Sonora with the Sierra La Madera, a Sky Island mountain range in the Madrean Archipelago. The study area is along the Hermosillo-Moctezuma highway about 30 km (by air) southwest of Moctezuma (between 29°36'39" to 29°39'06"N and 109°52'50" to 109°56'18"W). The climate of the area is dry tropical with mean maximum temperature of 29.8 °C during June and July, mean minimum of 12 °C in December and January, and mean annual temperature is

of 21.1 °C. Frost only occurs occasionally, and hard freezes like that of February 2-3, 2011, are very rare. Annual average rainfall is 460 mm (Instituto Nacional de Estadística y Geografía 2010). Subtropical dry forest, grassland, and open low forest are the vegetation types in the area (Instituto Nacional de Estadística y Geografía 2010). Subtropical dry forest corresponds to foothills thornscrub of Felger and others (2001) and Sinaloan thornscrub of Brown (1994). Open low forest is also called oak woodland or encinal. Trees and shrubs such as *Acacia constricta*, *A. occidentalis*, *Ceiba acuminata*, *Bursera* spp., *Havardia mexicana*, *Lysiloma* spp., *Ipomoea arborescens*, and *Prosopis velutina* characterize vegetation in the study area (fig. 1).

Methods

The study sites were selected by field trips to the area and using Google Earth satellite image (Image© 2010 Geo Eye. ©2010 Google. ©2010 INEGI). Selection criteria were the presence of well-differentiation vegetation patches in a landscape mosaic, and connectivity between them. Six sampling sites were visited in August, September, and October 2011. A floristic list was constructed using the *relevé* method (Müller-Dumbois and Ellenberg 1974). Plants were collected for identification using regional floristic literature, consultation with experts, and comparison with specimens in the University of Sonora Herbarium (USON). Voucher specimens were deposited into USON. Collections, observations, and images from the El Rodeo-Básora flora are available online in the Madrean Archipelago Biodiversity (MABA) database (Madrean.org).

Results and Discussion

A total of 120 taxa in 95 genera, and 41 families were documented in the El Rodeo-Básora area. The families with more taxa are Asteraceae (22), Fabaceae (16), Convolvulaceae (9), Cactaceae (7), and Solanaceae (5) (fig. 2). Asteraceae, Fabaceae, and Poaceae

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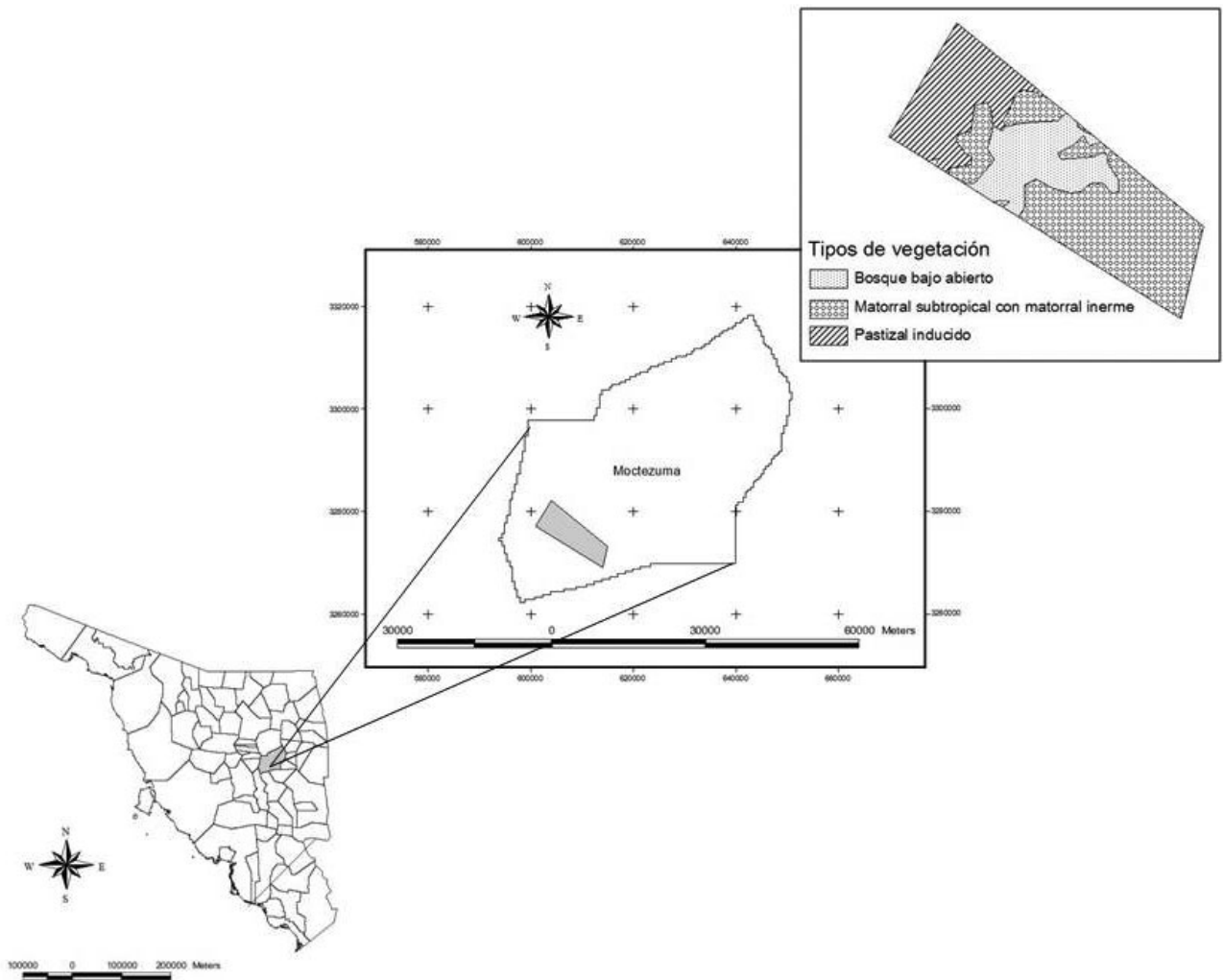


Figure 1—Study area and vegetation.

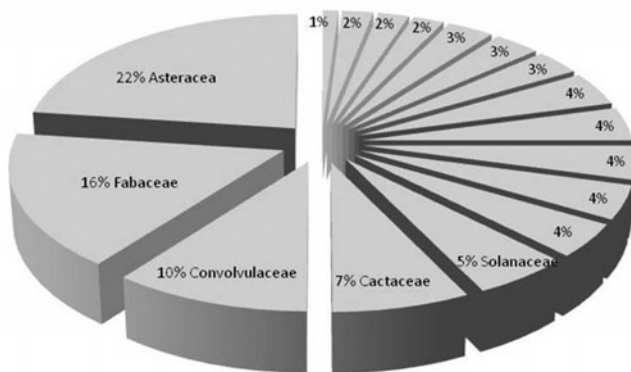


Figure 2—Dominant families in the El Rodeo-Básora area.

are the most speciose families in floras in Sonora (Van Devender and others 2010). Life forms of the taxa were classified according to Whittaker (1975) and (Krebs 1972): (a) trees—woody plants greater than three m tall; (b) shrubs—short, woody plant less than three m tall; (c) herbaceous—not woody plant above ground; (d) vines—woody vines or herbaceous vines; (e) epiphyte—plants that grow on other plants, but are not parasitic. Herbs with 62 taxa are the most common life form (fig. 3). The physical structure of the vegetation is defined by trees, shrubs, and large succulents (especially organpipe cactus [*Stenocereus thurberi*]). Trees with 17 taxa are much more diverse than in desert grassland, but only represent 14.2% of the flora. Some common plants in the transition between foothills thornscrub and oak woodland include *Ceiba acuminata*, *Fouquieria macdougalii*, *F. splendens*, *Ipomoea arborescens*, *Lysiloma divaricatum*, *Parkinsonia praecox*, *Prosopis velutina*, *Quercus chihuahuensis*, *Q. viminea*, and *Sabal uresana*. Floristic richness is threatened by cattle ranching and the introduction of exotic forage plants.

Four species in the El Rodeo-Básora flora have federal protection status in Mexico according to the NOM-059-SEMARNAT-2010 (DOF 2010). *Agave angustifolia* (Agavaceae) has a status of Amenazada (= Threatened), while *Amoreuxia palmatifida* (Bixaceae), *Crusea hispida* (Rubiaceae), and *Sabal uresana* (Arecaeae) have special status.

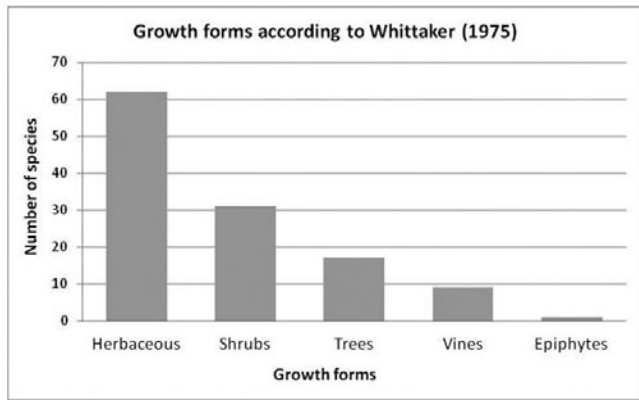


Figure 3—Dominant life forms of taxa in the El Rodeo-Básora area.

We conclude that the El Rodeo-Básora area is of special interest and conservation concern because of its mosaic of foothills thornscrub, desert grassland, and oak woodland, its floristic diversity, its role as a biological corridor connecting central Sonora landscapes to the Sky Island region, and the presence of four federally protected species.

Acknowledgments

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Association Between Nurse Plants and Saguaros (*Carnegiea gigantea*) in the Western Sonora

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Abstract—The objectives in this work were to determine nurse species associated with the saguaro, as well as the diversity of plant species in the saguaro patch. We also recorded the presence of termites on saguaro green tissues to evaluate their existence and possible causes for their presence. At each site a point-centered quarter transect was used, where the data on the closest saguaros were taken for size and height, percent litter soil coverage, and termite activity, as well as floristic composition, plant species cover, and the dimension of the associated patch of vegetation. Data on 55 saguaros showed the most common nurse species were *Larrea tridentata*, *Olneya tesota*, *Parkinsonia microphylla*, and *Ambrosia deltoidea*. Twenty-one (21) saguaro individuals were found distributed in different patches where *Olneya tesota* and *Parkinsonia microphylla* showed the most species diversity. Termite activity was present in saguaros with little or no litter cover in the soil. This is the first work focusing on the causes for the increase of termite invasion of live saguaro tissues.

Introduction

Cacti are a diverse family and include about 2,000 species, which are often endemic and unique elements of the arid and semi-arid areas of America (Drezner and Lazarus 2008; Godínez-Alvarez and others 2003; Hunt and others 2006). For most cacti, facilitation is undoubtedly one of the ecological biotic interactions most widely documented. Different species of perennial plants tend to favor germination of seeds and survival of seedlings of various species of cacti, leading to patterns of patches of strongly clumped species. A well-studied example is the interaction of saguaro (*Carnegiea gigantea*) with perennial trees and shrubs, where they facilitate the establishment of seedlings of saguaro. However, when the saguaro is an adult it can affect and compete with the nurse plant. Within the Sonoran Desert in Sonora, some of the most important nurse plants have been used for fuel, fencing, and crafts for a long time (Castellanos and others 2010a), despite that not much is known and many ecological aspects of this interaction still need to be studied. For example, Castellanos and others (2010b) have documented the interaction of termites, affecting green tissues of living saguaros, and propose this may be an important cause in the death of saguaros and possibly affecting its population dynamics. For such reasons, our research questions were:

1. What is the importance of nurse plants to the populations of saguaros?
2. Do patchiness diminish adverse biotic interactions? and
3. Are there other indirect effects such as amount of litter under the nurse plant that contributes to the saguaro not being invaded by termites?

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Materials and Methods

Sampled sites were located in the northwestern region of the State of Sonora, near Puerto Libertad. We selected three sites that had been previously sampled (Castellanos and others 2010b), in which populations of saguaro are well represented. The selection of saguaros was along transects using the point-centered quarter method, with a separation of 50 meters between each of them. At each point we sampled the nearest saguaro in each of the four quadrants. This method was used in each of the three sampling sites. After that, we measured saguaro height, coverage of the patch, floristic composition under the canopy of nurse species, and the amount of litter cover in the soil close to the basal area around the saguaros. To determine the age of saguaro, we used the formula proposed by Drezner (2002) in which saguaro growth relates to their age. For the application of the formula we required the calculation of a saguaro growth factor, which differs according to the area to be analyzed and which consists in measuring the population of saguaro during one year. We assumed a factor of 0.85, that seems to fit most other studies, in order to reduce the error when applying the formula.

Results and Discussion

Characterization of Saguaro (*C. gigantea*) Patches

We found a total of 21 species within different patches associated with saguaro. The main nurse plants associated to saguaro in our study region were *Olneya tesota*, *Parkinsonia microphylla*, *Ambrosia deltoidea* and *Larrea tridentata*. The last plant species allowed the establishment of 11 other species, but presented a large variability among all patches. There were patches where *L. tridentata* was the only species associated with saguaro, and others where it was associated with two to three different species. Patches with the largest diversity of species were under *P. microphylla* and *O. tesota*, and were related to the larger canopy cover from those patches.

Description of the Saguaro (*C. gigantea*) and Its Nurse Plants Populations.

The three study sites showed a similar population density with an average of 58.8 plants per hectare. Our data indicated that the number of saguaros sampled per site was sufficient to estimate the population density. The saguaro population structure had a progressive pyramid-like shape. This indicates a young saguaro population with a constant growth, and it is noteworthy that the most abundant saguaro size range was for plants between 0 and 1.5 meters in height, which means that the saguaro populations are dominated by juveniles in the three study sites.

The main plant species found as nurse plants of saguaro were *Larrea tridentata*, *Ambrosia deltoidea*, *Olneya tesota* and *Parkinsonia microphylla*, in decreasing importance. In addition we calculated the occurrence of facilitation by these four species and found that *Larrea tridentata* had the highest percentage (30.4%) on the three sites.

Percentage Litter Cover in Soil and Calculated Age of Saguaro (*C. Gigantea*) Studied

Litter cover in soil surrounding the base of saguaro of different ages changed or was not present, so there was no specific pattern or influence of the age of the saguaros with respect to percentage soil covered with litter even though that could have been influenced by the nurse plant to which it is associated. However, we found that older saguaros did not have any litter on the soil, perhaps because they do not already have a nurse plant that could provide such litter material, unlike the juvenile saguaros that had higher litter soil cover.

Absence or Presence of Termites at Saguaro (*C. gigantea*) Sites

We evaluated the susceptibility to invasion of termites in relation to the age of saguaros, and found that termite activity was higher between the age of 30 to 80 years. In the limits of the population of saguaros (13-118 years) did not show invasion by termites. This may be because young saguaros are sheltered and protected under the canopy of the nurse plants.

Based on the average from four measurements of percent soil litter cover, we found that individuals with low percent soil litter cover (0 to 30%) were more susceptible to invasion in the tissues of the saguaro by termites. It was further noticed that there was a 1:1 ratio for individuals with low percent soil litter cover, indicating that termites do not always tend to invade the saguaro that does not have a noticeable percentage of soil litter cover. Also, we found that the main nurse plants species (*Olneya tesota*, *Parkinsonia microphylla*,

Ambrosia deltoidea and *Larrea tridentata*) did not present difference on the organic matter despite the form of life (tree or shrub) and its canopy coverage.

Conclusions

The main nurse plants for saguaro in our study area were *Olneya tesota*, *Parkinsonia microphylla*, *Ambrosia deltoidea* and *Larrea tridentata*, which differ in their role within the studied populations. Their nurse contribution depends mainly on the size of the patch and therefore, the diversity of species associated with nurse plants. We found 21 species primarily associated with the evergreen plants *Olneya tesota* and *Parkinsonia microphylla* including saguaro. *Larrea tridentata* was a common nurse plant species for saguaro in the three sites. The ecological and ecophysiological relations of a nurse species to the saguaro population dynamics are a focus of more studies to understand the many details about these interactions that occur in arid and semiarid lands. The percentage litter cover in the soil provided by the nurse plant, and the species under it, seem to work as a defense mechanism for saguaros against herbivore attack by termites. It was found that termites do not invade saguaros with larger litter cover of soil at their base, meaning that the absence of litter is related to the invasion of termites, although other mechanisms may also be responsible for termite invasion to living green tissues of saguaro.

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Vegetation Monitoring on Semi-Arid Grasslands Ungrazed by Domestic Livestock

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Abstract—The Research Ranch is an 8000-acre sanctuary and research facility in the semi-arid grasslands of southeastern Arizona, USA. Cattle were removed from the property in 1968 to provide a reference area by which various land uses, such as grazing and exurbanization, could be evaluated. Vegetation transects were established in 2000 and 2003 on several ecological sites in Major Land Resource Area 41. This monitoring program has tracked changes after wildfires and during drought. Trends associated with non-native, invasive species, particularly *Eragrostis lehmanniana* (Lehmann lovegrass) and *E. curvula* (Boer lovegrass) have been documented. For example, in an 8-year span, the frequency of Lehmann lovegrass on one loamy upland site grew from 1% to 60% at the expense of the native *Eragrostis intermedia* (Plains lovegrass) and *Bouteloua gracilis* (Blue grama). Results from monitoring provides feedback to Audubon personnel in the management of the property and are shared with other land managers to help tease apart the effects of grazing and other land use actions from the effects of climate.

Introduction

The Appleton-Whittell Research Ranch is an 8000-acre enclosure from which domestic livestock were removed in 1968. The facility is a cooperative effort among several landowners including the Bureau of Land Management, U.S. Forest Service, Resolution Copper Company, The Nature Conservancy, The Research Ranch Foundation, and National Audubon Society, and is managed by Audubon under contractual agreements with each. The Research Ranch is primarily Madrean mixed grass prairie. Its lands are tributary to the Babacomari River. Audubon staff work closely with the members of the cattle ranching community and ranchers are able to compare their management efforts with an ungrazed reference area. Many research projects have resulted from work conducted on the Research Ranch but vegetation monitoring has been a relatively recent addition to the scope of activities.

Methods

Eighteen vegetation transects were established in 2003 and 2004 based on the work by Breckenfeld and Robinett (2001). Transects were located in representative areas within Ecological Sites. The Plant Frequency method (Despain and others, 1997) is used to gather

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vegetation data. Four parallel lines of 50 frames each yield 200 frames to determine frequency. Three points per frame are used to establish cover (data not shown). Simple rain gages are located at or near each transect and read twice per year.

Results

Data from a subset of four transects established in loamy uplands are summarized along with precipitation data (fig. 1) and some generalizations across all transects.

Transect 650

This transect is on the western side of the Research Ranch and exhibits a 15% SW slope. The Ryan Fire burned this area in April

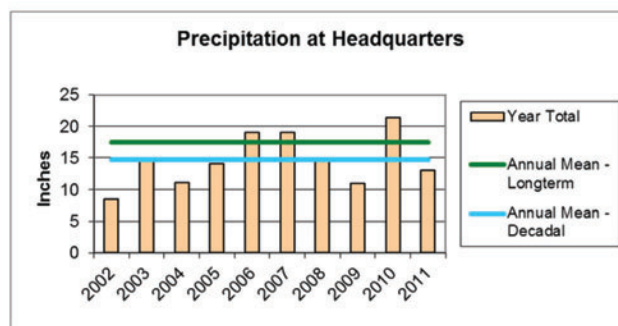


Figure 1—The cumulative shortfall (long-term mean—actual precipitation) during the 9 years represented by this report equals 24 inches.

2002 during severe drought. Recent precipitation: Monsoon 2010: 14.7 inches; Winter 10/11: 0.8 inches; Monsoon 2011: 6.7 inches. Frequency of sideoats grama (*Bouteloua curtipendula*) has been stable or increased (fig. 2), but blue grama (*B. gracilis*) crashed in 2006 and has not recovered. Wolftail (*Lycurus setosus*) is increasing and curly mesquite (*Hilaria belangeri*) is maintaining despite the dry winter of 2010/11.

Transect 651

This site is on the western side of the Research Ranch and has a 2% E slope. This transect also burned in the Ryan Fire of April 2002. Recent precipitation: Monsoon 2010: 12.5 inches; Winter 10/11: 1.5 inches; Monsoon 2011: 7.1 inches. Lehmann lovegrass (*Eragrostis lehmanniana*) is exhibiting its invasive potential on this transect (fig. 3), increasing from 1% frequency in 2003 to 55% in 2006, and is retaining dominance. Both blue grama and plains lovegrass (*E. intermedia*) show declines during this period. Wolftail is increasing on this transect.

Transect 706

This site is also on the eastern side of the research ranch. Slope is 12-15% E. This plot burned in the Ryan Fire of April 2002. Recent precipitation was: Monsoon 2010: 11.7 inches; Winter 10/11: 0.9 inches; Monsoon 2011: 10.6 inches. NRCS had established and read this transect in 1997 using the same protocol, so we were able to compare changes and trends for a longer time period. Curly mesquite was dominant in 1997 (96%), but found in only 2 frames (1%) in 2011 (fig. 4). Frequency of cane beard grass (*Bothriochloa barbinodis*) is trending upward, 18% to 52%. Lehmann lovegrass was found at low frequencies (2-3%) from 1997 through 2005 before peaking at 41% in 2009. Complete plant mortality for this species brought the frequency down to 10% in 2011. In 1997, plains lovegrass was noted in 26% of the frames. By 2011 none was recorded.

Transect 665

This transect has a slight (1-3%) northern exposure. This plot burned in the Ryan Fire of April 2002 and the Canelo Fire of May 2009 (also

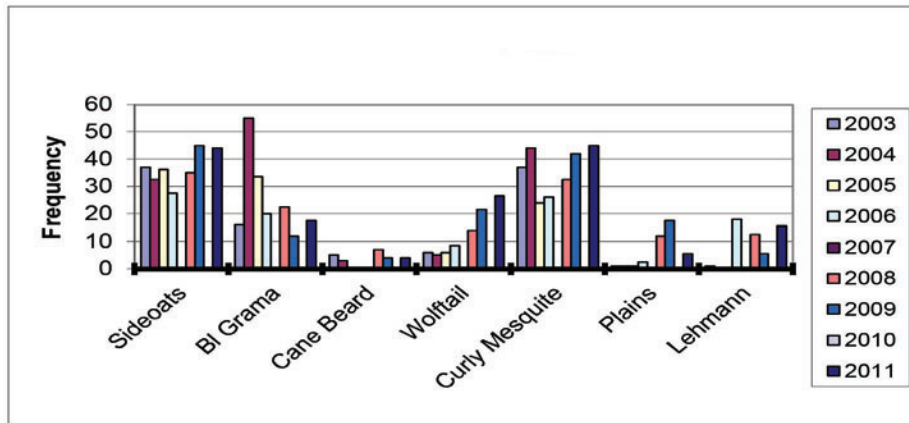


Figure 2—Loamy upland transect 650.

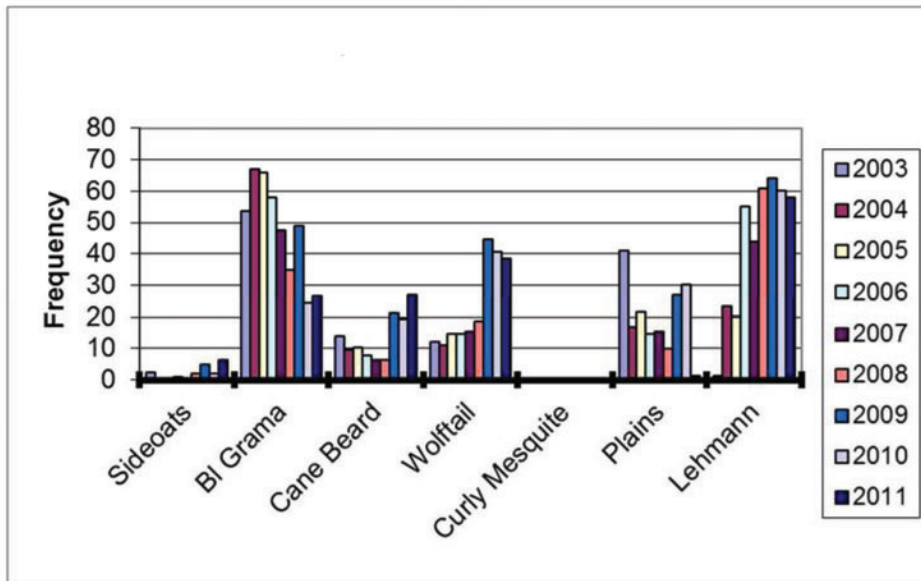


Figure 3—Loamy upland transect 651.

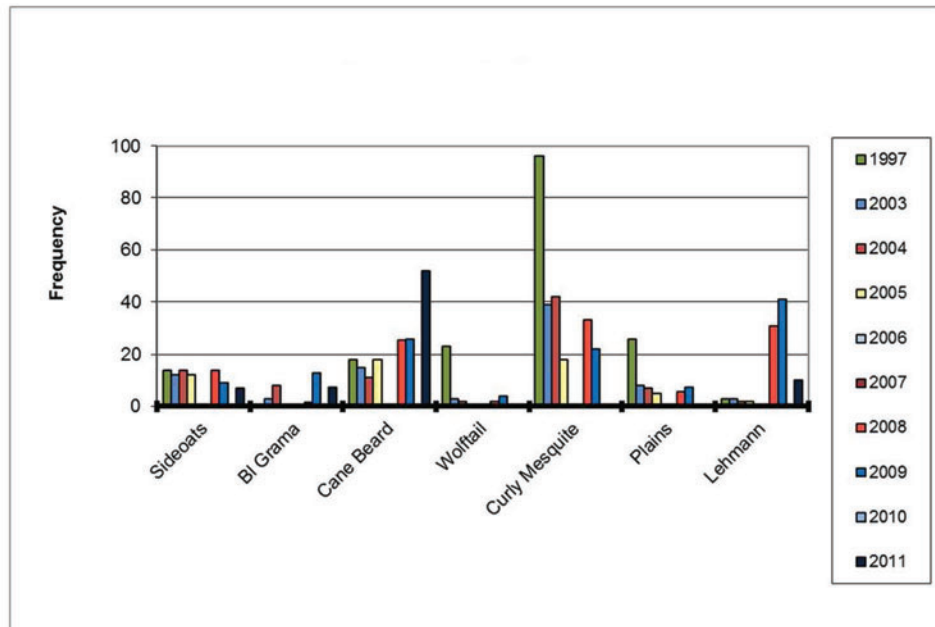


Figure 4—Loamy upland transect 706.

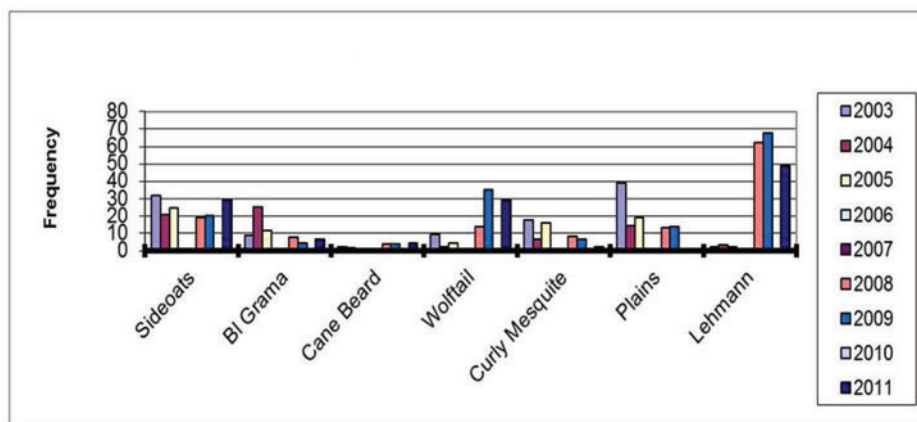


Figure 5—Loamy upland transect 665.

a drought year). Recent precipitation: Monsoon 2010: 13.0 inches; Winter 10/11: 1.0 inches; Monsoon 2011: 7.7 inches. Plains lovegrass has exhibited a steady decline during this period, from 39% frequency in 2003 to 0% in 2011 (fig. 5). Lehmann lovegrass was found at low levels until 2006 (62%). Curly mesquite declined from 16% to 2%.

Conclusions

We established/re-established sixteen transects in 2003 and added two more in 2004. The transects experienced a range of fire activity and all have been influenced by drought conditions. This is a monitoring project rather than a research project, so care must be taken to assign causality, but two iconic native grasses, plains lovegrass and blue grama have exhibited a steady decline in frequency and the trend for the non-native, Lehmann lovegrass is upward. It was hoped that

grassland protected from grazing by livestock would be resistant to invasion by non-native grasses, but this hope has proved groundless. Other methods must be used if the objective is to protect and maintain native plant species diversity.

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Mountain Pine Beetle in Southwestern White Pine in the Pinaleño Mountains

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Abstract—Mountain pine beetle has rarely been found in the Madrean Sky Island Archipelago and has not been reported from the Pinaleño Mountains until recently. This insect began killing southwestern white pine in 1996 or earlier, with additional mortality each year since. Activity has increased in the last 2 years. The life cycle in the Pinaleños during this time has been univoltine, with some females surviving the winter to produce a second brood in the spring. Stain fungi are evident in most killed trees, but not all. In infested areas, total stocking and the abundance of southwestern white pine has been significantly reduced, creating small openings in the stand canopies. The future course of this outbreak is uncertain.

Introduction

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae, Scolytinae)) is a native bark beetle infrequently found in the Madrean Sky Island Archipelago, and there is no record of it in the Pinaleño Mountains (32.4° latitude). Scattered mountain pine beetle-infested southwestern white pines (*Pinus strobiformis*) were found in 2007 near Soldier Creek in the Pinaleño Mountains (USDA Forest Service 2008). Additional individual and small groups of southwestern white pines have been infested each year since. Mortality each year is minor, but the outbreak has persisted, damage appears to be increasing, and mortality has accumulated to significant levels that affect resource values. Values at risk include recreation, as some of the infestations are in the vicinity of developed recreation sites, and wildlife, as the seeds, large trees, and snags are utilized by the endangered Mount Graham red squirrel, *Tamiasciurus hudsonicus grahamensis* (Benkman and others 1984; Frank and Cox 2009), among others. Though mountain pine beetle is the most significant insect disturbance agent in lodgepole pine (*Pinus contorta*) forests, and is well studied elsewhere, little is known about its biology and effects in southern Arizona or on southwestern white pine. We undertook investigations to characterize the effects of infestation, determine tree and site characteristics associated with mountain pine beetle infestation, and establish a timeline of outbreak development

Background

Though well distributed throughout much of western North America (Gibson and others 2009; Safranyik and others 2010; Wood 1982), records of mountain pine beetle and related tree mortality are sparse in southern Arizona. Hopkins (1909) reported finding it in the Chiricahua Mountains in 1907, but reported no further information from that location. A tabulated Forest Service record of forest insect activity during the 1960s in Arizona and New Mexico (USDA Forest Service 1971) indicates that an infestation occurred on the Coronado National Forest (N.F.) in the 1960s, at the same time that outbreaks occurred on the Cibola N.F. and Carson N.F. in New Mexico. Though survey records from individual years in the 1960s are no longer available, the information indicates that infested trees were on these three National Forests and included ponderosa pine (*Pinus ponderosa*) and southwestern white pine in 1961-1965, 1968, and 1969. The only other insect activity recorded for the Coronado N.F. during that time period was roundheaded pine beetle (*Dendroctonus adjunctus* Blandford) in 1967-1970. No further reference to mountain pine beetle activity in southern Arizona was found until 2007.

The historical range of mountain pine beetle extends from northern Baja, California, and the northern border of Mexico (31° latitude) to central British Columbia (56°) (Cibrián-Tavar and others 1995; Safranyik and others 2010; Wood 1982). As a result of rising temperatures, the geographic range has recently expanded northward to eastern Alberta (Safranyik and others 2010) and to higher elevations (Bentz and others 2011; Logan and Powell 2009). Activity within the historical range has also increased in recent years, and outbreaks are occurring in areas where they either were not recorded or were recorded infrequently (Bentz and others 2011; Bentz and Schen-Langenheim 2007; Gibson and others 2009). The current outbreak in British Columbia and Alberta is likely one of the largest in history (Kurz and others 2008; Taylor and others 2006). All *Pinus* species within the mountain pine beetle range except Jeffrey pine (*Pinus jeffreyi*) can be successfully attacked, including white pines and piñons.

In: Gottfried, Gerald J.; Ffolliott, Peter F.; Gebow, Brooke S.; Eskew, Lane G.; Collins, Loa C., comps. 2013. Merging science and management in a rapidly changing world: Biodiversity and management of the Madrean Archipelago III; 2012 May 1-5; Tucson, AZ. Proceedings. RMRS-P-67. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Temperature regimes play a significant role in determining when and where mountain pine beetle outbreaks occur (Gibson and others 2009; Logan and others 2010), and rising temperatures may have contributed to recent changes (Bentz and others 2011; Safranyik and others 2010) by influencing seasonal aspects of life history (Logan and Bentz 1999). In order to overcome tree defenses, adult mountain pine beetles must mass-attack trees with large numbers of beetles. Synchronized adult emergence and aggregation pheromones make it possible for sufficient numbers of beetles to be present at one time to overcome tree defenses. Mountain pine beetle can adapt its development rates seasonally to optimize likelihood of synchronized emergence (Logan and Bentz 1999). Throughout its wide geographic range, mountain pine beetle has adapted to local temperature regimes and has the capacity to exhibit different seasonal life histories (Amman and Bartos 1991; Gibson and others 2009). Mountain pine beetle does not have a winter diapause, and the life history is very responsive to temperature. Mountain pine beetle is typically univoltine, but in portions of its range with cooler summers (especially at high elevations), it is semivoltine (Safranyik and Carroll 2006). Outbreaks occur during warm periods, particularly when winter temperatures are mild enough to allow survival of all life stages, and there is sufficient summer thermal energy to allow a univoltine life cycle (Logan and others 2010) and when temperature regimes facilitate synchronous adult emergence (Bentz and others 1991; Safranyik and Carroll 2006); suitable thermal windows may be quite narrow. The northern part of the Madrean archipelago is the southern extreme for the mountain pine beetle range, and the thermal habitat is probably marginal for the species. Most of the time, activity is probably minimal because synchronization of adult emergence is insufficient to allow mass-attack, a univoltine life cycle is infrequent, or mortality occurs to one or more life stages because summer temperatures are too warm or because an overwintering stage is susceptible to cold. One or more of these conditions has probably changed recently.

Approach

Our objectives were to characterize the effects of infestation, determine tree and site characteristics associated with mountain pine beetle infestation, and establish a timeline of outbreak development. Our approach was to establish plots in infested areas, compare the character of those plots to randomly located southwestern white pine-inhabiting plots, and date mortality of mountain pine beetle-attacked trees using tree-ring analysis.

Infested areas were located by reconnaissance both on foot and by vehicle. Plots were located completely within infested areas. Where infested areas were large, plots were located 100 m apart, and along an elevation gradient where possible. Trees larger than 20 cm DBH were measured on a 0.05-ha plot fixed-radius plot while trees smaller than 20 cm DBH but 3 cm DBH or larger were measured on a 0.02-ha fixed-radius plot. At each plot, spatial coordinates, elevation, aspect, slope, and species of trees in the vicinity were recorded. Data recorded for each tree included species, diameter (DBH, or DIB if bark was absent), dwarf mistletoe rating, canopy position, needle color and abundance on live and dead trees, presence of bark and limbs of various sizes on dead trees, evidence of bark beetle attack, species of attacking bark beetle, and evidence of stain fungi. When recording canopy position we distinguished between small suppressed trees and healthy understory trees. There are many bark beetle species that attack *Pinus* in southern Arizona, but mountain pine beetle galleries are distinctive and easily distinguished from those of other species (fig. 1a; Fairweather and others 2006). We had little difficulty finding evidence of mountain pine beetle activity in trees that had been

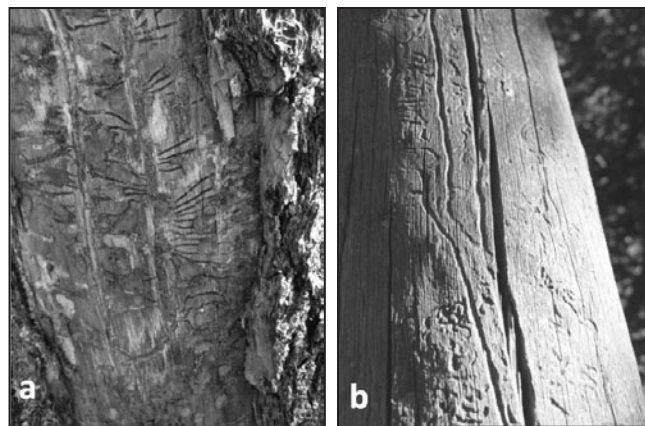


Figure 1—(a) Fresh mountain pine beetle galleries, and (b) gallery scars from a tree killed in 1997 and photographed in 2011; both are southwestern white pine in the Pinaleno Mountains. Mountain pine beetle females construct long nearly-linear galleries with J- or L- shaped hooks at the bottom, along which eggs are laid; larvae feed in the phloem and construct galleries that initially are horizontal and do not score the wood (photos by A.M. Lynch).

dead for 15 years (fig. 1b), as mountain pine beetle scores the wood surface and these scars are evident after much weathering. Increment cores were taken from mountain pine beetle-killed trees that had been dead long enough that the attack year could not be determined from visual inspection of snag condition, as well as from some recently-killed trees. The outer ring dates of these cores were determined in the laboratory using standard tree-ring procedures (Stokes and Smiley 1968). We also opportunistically sampled individual mountain pine beetle-killed trees found during reconnaissance to assist in determining the outbreak timeline.

Characteristics of mountain pine beetle-infested trees and plots were compared to tree and plot characteristics of systematically located plots in a Pinaleno Demography study (Falk and others 2009) on which southwestern white pine was found. The Pinaleno Demography plot system consists of two sampling grids across the mountain range above 2134 m elevation. The first grid is spaced at 1000 m, and the second grid is offset east and south by 500 m. Plots consist of nested 0.017- and 0.05-ha plots for small and large trees, respectively. At each plot, site and stand characteristics data were collected in 2009 and 2010 similar to what is described above for live and dead trees of all species. Additionally, increment cores were collected from each tree and cross dated and measured to establish demographics, mortality events, growth release events, and recruitment events.

We did not set out to investigate the life cycle and seasonal history of mountain pine beetle in the Pinaleno Mountains. However, during the last several years the first author has repeatedly visited infested trees and plots several times to monitor the situation, assist other investigators in the collection of genetic material and infested bolts for life history studies, train local managers in identifying mountain pine beetle, and to develop this study. These observations are also reported here.

Mountain pine beetle-infested areas were located below the Riggs Lake campground, in and above the Treasure Park campground, on the upper slopes of Webb Peak, and in the Soldier Creek campground. District personnel had removed many dead and infested trees at the latter location for safety reasons, and we sampled six plots in the other locations. Here we report the results from those plots, and are careful

to not over interpret the limited data, restricting our observations to what we think can be supported by the data. In 2012, we will sample additional plots and determine the causal agents of dead southwestern white pine found in the Pinaleno Demography study.

Results

Insect Biology

The majority of the mountain pine beetle population was clearly univoltine with mass-attacks in the autumn. A small number of trees were successfully mass-attacked in spring. This was evidenced by very tight bark in trees with excessive sap flow on the outer bark in spring, presence of pupae in early June 2011 (indicative of spring attacks the previous year [B.J. Bentz, personal communication]), noticeable fading of foliage in some trees in autumn (fading from autumn attacks usually occurs early in the subsequent growing season), and formation of a partial growth ring in the outer ring of a few dead trees. Our data is not sufficient to accurately determine the proportion of trees that were attacked in spring (it was low, perhaps 10-15%) or if a portion of the population was semivoltine.

Evidence of stain fungi was found in most trees, but not all. We did not record the presence of staining at the beginning of the study. Twenty-five percent of sampled southwestern white pine and ponderosa pine (on the plots or not) and 12% of the cored trees did not have stain fungi. Stain-free trees were killed in a range of years from 1998 to 2011.

Outbreak Development

We originally thought that the outbreak originated at the summit of Webb Peak in lightning-struck trees, but this was not the case. Individual dead trees with outer ring dates of 1996 and 1997, which for autumn-attacked trees would be the year-of-attack, were found scattered across the landscape. Larger numbers of trees were attacked in 2001 and especially 2010. This is typical of mountain pine beetle—randomly distributed impaired trees are attacked when population

densities are low, but once population density increases beetles select clustered populations of larger resource-rich trees (Boone and others 2011).

Character of Infested Trees

Fifty-four mountain pine beetle-attacked trees were found, including 14 opportunistically sampled (off-plot) trees. All were southwestern white pine except for two ponderosa pine and one Douglas-fir (*Pseudotsuga menziesii*). The Douglas-fir probably represents a mistake by attacking beetles, as it was growing tightly intertwined with a similarly sized southwestern white pine (both were 13 cm DBH). Brood developed in the southwestern white pine, but not in the Douglas-fir. All attacked trees were larger than 17 cm DBH except for these two trees, and the majority were larger than 20 cm.

On infested plots, a greater proportion of larger size classes were attacked (fig. 2). Over 70% of trees 40 cm or larger in diameter were killed by mountain pine beetle.

Character of Infested Plots

The Pinaleno Demography plot system (Falk and others 2009) represents a random sample of sites in the Pinaleno Mountains above 2134 m. On plots with southwestern white pine, it is most commonly associated with Douglas-fir, white fir (*Abies concolor*), and ponderosa pine (89, 51, and 49% of plots, respectively). Engelmann spruce (*Picea engelmannii*), corkbark fir (*A. lasiocarpa* var. *arizonica*), and aspen were less frequently found (31, 31, and 26% of plots, respectively), and Gambel oak (*Quercus gambelii*) and Arizona willow (*Salix arizonica*) were found occasionally. Southwestern white pine inhabited sites with slopes less than 65% with a wide range of aspect, though few faced west.

Species composition, slope, and aspect of mountain pine beetle-infested plots were very similar to those of the Pinaleno Demography plots. Elevation ranged from 2670 to 3050 m. Southwestern white pine stocking of infested plots varied considerably, between 5 and 36 sq m/ha, and stocking of all species varied between 34 and 73 sq m/ha. Douglas-fir was found on all infested plots

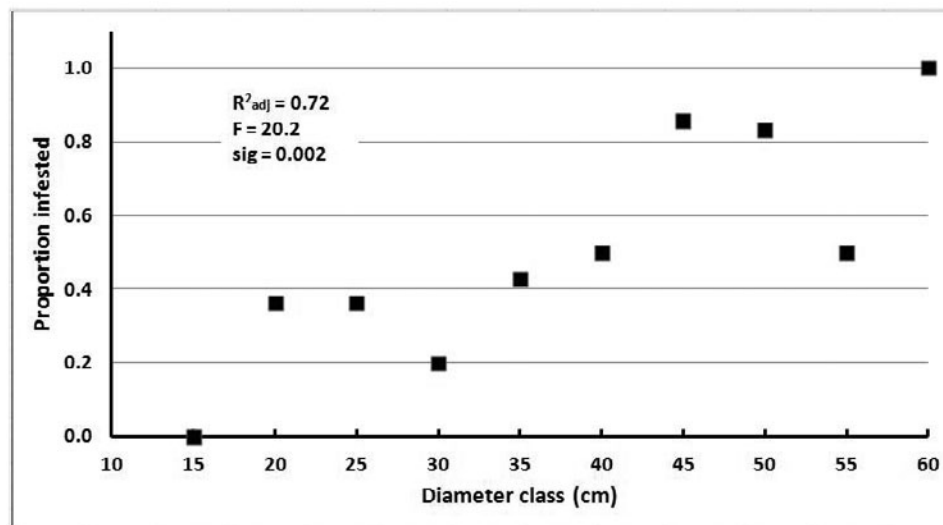


Figure 2—Proportion of southwestern white pine infested with or killed by mountain pine beetle on infested plots. Each size class, 15-50 cm, had 6 or more trees.

Table 1—Characteristics of study plots before and after mountain pine beetle infestation, and plots in the Pinaleno Demography study where southwestern white pine was present.

	Before	After	Change (%)	Demography
All species				
stocking (sq m/ha)	49 ± 17	19 ± 5	-61	96 ± 39
density (tph)	660 ± 214	537 ± 193	-19	698 ± 335
Southwestern white pine				
stocking (sq m/ha)	27 ± 9	14 ± 11	-48	20 ± 19
density (tph)	360 ± 135	240 ± 153	-33	152 ± 102
dominance (% stocking)	55 ± 9	37 ± 18	-32	22 ± 20
mean dbh (cm)	29.2 ± 7.5	28.0 ± 8.7	-4	39 ± 11

On average, infested plots had similar densities but half the basal area compared to the random Pinaleno Demography plots. There was a higher representation of southwestern white pine that were, on average, smaller in diameter than those in the Pinaleno Demography study (table 1).

Effects of Infestation

Mountain pine beetle infestation significantly reduced total stocking and density, and the abundance of southwestern white pine (table 1). Mean basal area was reduced approximately 60%, creating small openings in the canopy. Resulting species composition favored Douglas-fir, with mean dominance by that species increasing from 22 to 56%.

Discussion

Some conclusions can be made from the study at this point. In the Pinaleno Mountains, mountain pine beetle preferred areas dominated by southwestern white pine indicates that insect attacks occur where the host is more abundant. We found few ponderosa pine that were attacked by mountain pine beetle, even in areas where ponderosa pine was common.

The overall impacts of this insect have been modest, creating small openings in mixed-conifer stands. Southwestern white pine is prolific in the Pinaleno Mountains, with abundant reproduction. It is one of the preferred species for several resource objectives, and has been a stable component of the mixed-conifer forest. Though damage has been modest to date, it increased significantly in 2010 and 2011.

Uncertainty regarding the future course of the outbreak is the largest concern. Mountain pine beetle has aggressive population dynamics once population densities are high enough that the defenses of healthy trees can be overcome (Boone and others 2011; Gibson and others 2009), and once started, outbreaks can deplete the host resource over large areas. The initial stages of outbreaks are marked by a change in attack behavior from individual impaired trees to groups of healthy trees, which appears to be the case in the Pinalenos. Attacks in the last 2 years have clearly favored groups of healthy trees; however, the scale of activity in the Pinalenos is rather small, so it is too soon to conclude that a high-intensity outbreak has begun. Outbreaks occur in warm periods when the population can sustain a univoltine life cycle (Logan and others 2010), and that appears to be the situation in the Pinalenos. On the other hand, the temperature regime needed to sustain that life cycle in southern Arizona is unknown. The thermal habitat for mountain pine beetle may be marginal, and it is possible that small changes in the temperature regime could disrupt

the univoltine life cycle and synchronization of adult emergence, which would subsequently dampen outbreak dynamics. Activity in the 1960s apparently subsided without catastrophe. Too little is known about the course of that outbreak to assist in projecting mountain pine beetle activity during the current outbreak. We cannot determine if the mountain pine beetle population in the Pinalenos is at an incipient outbreak stage or in the initial stage of an intense outbreak.

Acknowledgments

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Population Status of Prairie Dogs (*Cynomys ludovicianus*) in the San Pedro River Basin, Sonora

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Abstract—The black tailed prairie dog (*Cynomys ludovicianus*) is a species of conservation concern for Mexico, the United States and Canada. Populations in Mexico (including those in Sonora), which are considered endangered by the Mexican authority, require additional conservation efforts to maintain them on the long term. Our objective was to determine population size and density of the colonies in Sonora, as a first step to translocate individuals into a new colony in the region (Los Fresnos Ranch). The size of prairie dog colonies is 93 ha for La Mesa and 58 ha for Las Palmitas. La Mesa was surveyed between November 2010 and December 2011, and Las Palmitas from May to December 2011. Density was calculated with distance-based transect counts, using sampling software (Distance 4.0) for the analysis of the data. Our density estimates for La Mesa range from 1.03 to 5.29 individuals/ha, with an estimated peak population size of 488 individuals. In Las Palmitas, densities ranged from 1.50 to 6.45 individuals/ha, with an estimated peak population size of 362 individuals. Our results suggest that a controlled but limited translocation effort will allow the establishment of a new colony at Los Fresnos without compromising the long-term persistence of extant colonies.

Introduction

Prairie dogs (*Cynomys* spp) are considered keystone species as they contribute to increase regional biodiversity (Ceballos and Pacheco 2000; Cully and others 2010; Royo-Marquez and Baéz-Gonzalez 2001; Winter and others 2002). The genus *Cynomys* is restricted to North America and includes five species of which two occur in Mexico: the Mexican prairie dog (*C. mexicanus*) and the black-tailed prairie dog (*C. ludovicianus*). Black-tailed prairie dogs in Mexico are distributed in two populations (Ceballos and Pacheco 2000), one in the grasslands of northwestern Chihuahua (Ceballos and Mellink 1993) and the other in northern Sonora (Castillo 2004).

Currently, this species is present in 2% of its historical range (Ceballos and Mellink 1993; Ramirez and Keller 2010). Population declines have been partially attributed to poor livestock husbandry and agricultural practices that result in the loss, fragmentation, and disturbance of natural habitats; poisoning campaigns, plague (*Yersinia pestis*), and recreational shooting (Hoogland 2006; Ramirez and Keller 2010) have also contributed to declines. Prairie dog population declines have been relatively well documented for northwestern Chihuahua

(Avila and others 2012) but little is known about population changes in northern Sonora. The two colonies in Sonora are located on the edge of their distribution (Hoogland 1996) so that their abundance may be lower than those presented in the distribution center (Lawton 1993). The colonies have no genetic connectivity with the colonies of Chihuahua and, in the case of Arizona, were considered extirpated long ago (Knowles and others 2002). Although recent mapping efforts indicate that the prairie dog colony in La Mesa Ranch lost 60 ha (34% loss) between 2004 and 2011 (Moreno-Arzate and López-González 2012), no study has documented changes in population numbers in Sonora. Our objective was to determine the population status of the only two colonies left in Sonora, La Mesa and Las Palmitas, based on visual counts and distance-based methods. With this information, we expect to determine whether these populations are able to support extractions of individuals for translocation efforts in the region.

Study Area

The study area is located near the international border between Sonora and Arizona in the upper San Pedro River Basin. The colonies are located between parallels 30°37'12" and 31°19'48" N, and between meridians 109°48'36" and 110°37'12" W (fig. 1). This area is dominated by Chihuahuan desert grasslands. Elevation ranges between 1400 and 1500 m with an average annual rainfall of 300 to 750 mm. The area has been impacted by livestock pressure causing changes in the structure and composition of plant communities, including an evident spread of mesquite (Castillo 2004).

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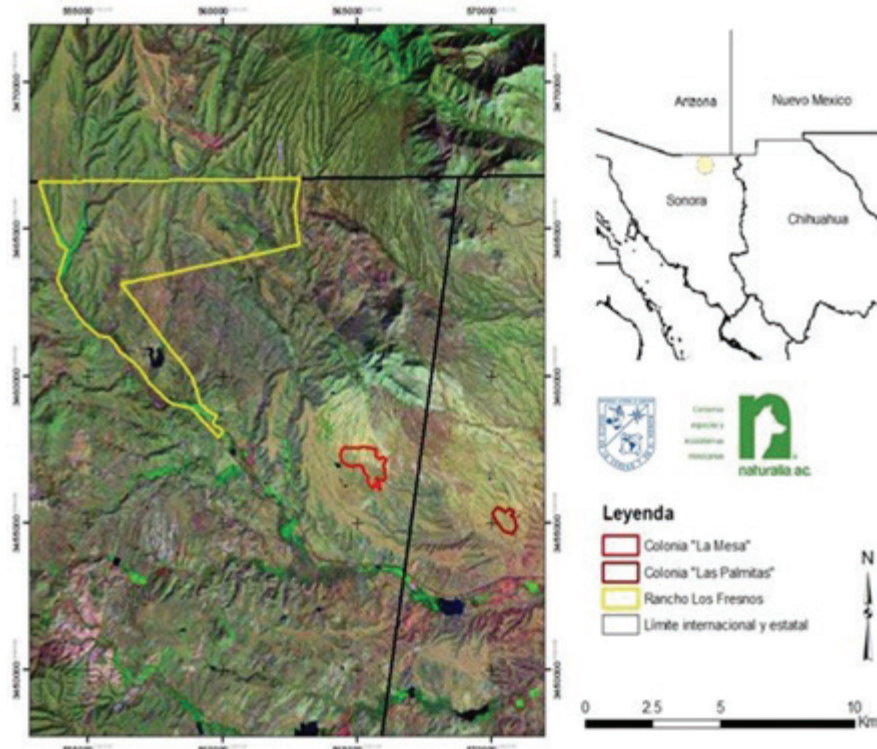


Figure 1—Geographic location of black-tailed prairie dog colonies in Sonora.

Methods

La Mesa was surveyed between November 2010 and December 2011, and Las Palmitas from May to December 2011. We used strip transects (Burnham and others 1980) delineated approximately through the center of each colony to conduct visual counts of prairie dogs. The transect length in the colony of La Mesa was 2100 m, while the transect in the colony at Las Palmitas was 1100 m long. Each transect was surveyed twice a day, once between 0700 and 0800 hr and once between 1400 and 1500 hr for 2 consecutive days. We slowly walked each transect and recorded both the position and distance of each individual prairie dog during our daily surveys.

The distance from the observer to the observed prairie dog was calculated using a rangefinder. We also recorded the distance from the start of each transect to the observation point, documenting the position of the animal to either left or right side of the transect. We used the program Distance v4.0 (Thomas and others 2005) to estimate the population density within each colony. We identified significant changes in density throughout the year comparing monthly data with one-way ANOVAs.

Results

Density

The highest density at La Mesa was documented in March (5.0 individuals/ha) and July (5.3 individuals/ha). However, we found significant differences among sampled months throughout the study period ($F = 11.90$, $df = 11$, $p = 0.0001$). In the case of Las Palmitas, we documented the highest densities in September and July (6.3 and

4.5 individuals/ha, respectively) and the lowest in November (1.2 individuals/ha). Significant differences ($F = 21.7$, $df = 6$, $p = 0.0001$) between the months are shown in figure 2.

Population Size

After the surveys at colony La Mesa and using the highest monthly density (July with 5.29 individuals/ha), we estimated a peak population size of 488 individuals. The highest density at Las Palmitas produced a peak population size of 362 individuals during September.

Discussion and Conclusions

During the months from May to July, the densities calculated in La Mesa and Las Palmitas colonies showed an increase that coincided with the beginning of the rainy season and continued after heavy rainfall from July to September. This finding could be attributed to an increase in pasture growth, available biomass, reflected in the prairie dogs feeding activity (Hoogland 1996, 2003) and an increase in the activity of juveniles. A different pattern was observed for the months closer to the winter, where cold temperatures and the available biomass decreases, which caused a decrease in activity.

Population size estimated for both colonies confirmed that it is possible to carry out the translocation of individuals to create a new colony in the region. In the case of the colony La Mesa, which presents a population estimate above 400 individuals, this number allows the extraction of a group of prairie dogs that could range between 60 to 100 individuals. The latter number, which represents about 25% of the estimated population, might be interpreted as the number of prairie dogs that can be extracted without having a demographic impact on

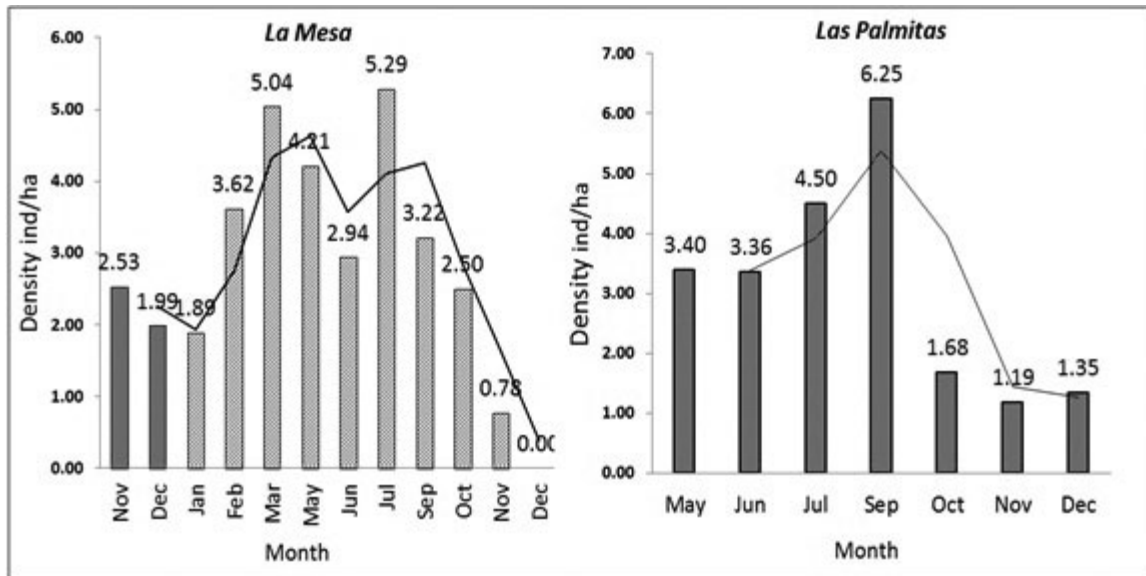


Figure 2—Monthly density estimated for the two prairie dog colonies surveyed in Sonora, Mexico.

the founder colony (Robinette and others 1995; Dullum and others 2005). Similarly, a translocation effort could be supported by the Las Palmitas colony as it has a population of over 350 individuals in which one could draw between 70 and 90 individuals ($\leq 25\%$) without compromising the long-term sustainability of that colony. It is important to continue monitoring in both colonies to estimate trends in the population and identify the most appropriate dates where all the necessary elements for a successful translocation may occur.

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Babocomari River Riparian Protection Project

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Abstract—The Babocomari River is a major tributary of the San Pedro River in Santa Cruz and Cochise counties, Arizona. This 140,000 acre catchment includes rolling grasslands on the Sonoita plain, oak woodlands in the Canelo Hills and the pine-oak forests of the northwestern Huachuca Mountains. The Babocomari River runs for 22 miles from its headwaters near Sonoita at 5000 feet elevation, eastward to join the San Pedro at Fairbanks at an elevation of 3850 feet. The U.S. Geological Survey estimates that this important tributary contributes about 6000 acre-feet of water annually to the San Pedro River system. The Arizona Department of Water Resources funded this 5-year study with a grant (09-164WPF) in 2009. Monitoring transects were installed in 2009 and 2010 and will be re-read each year through 2013. Objectives: Construct 2 miles of riparian boundary fence to restrict access by livestock from the Babocomari River. Install six stream riparian vegetation and geomorphic monitoring transects and six vegetation and geomorphic transects on riparian grasslands (sacaton) on tributaries to the Babocomari River. Analyze and summarize data annually and present that information to the participating ranch properties for use in making management decisions. Riparian monitoring stations were established in May of 2010 at three locations along the Babocomari River below the Babocomari Ranch (BR) headquarters and at three locations in June of 2010 on the Appleton-Whittell Research Ranch (ARR) of the National Audubon Society. These riparian monitoring transects were re-read in June of 2011. Riparian grasslands include large bottomlands of giant sacaton (*Sporobolus Wrightii* Monro ex Scribn) on both the BR and the ARR. Riparian grassland monitoring stations (three on each property) were established in the fall of 2009, re-read in 2010 and 2011. In addition to this monitoring effort the Babocomari Ranch has begun to protect private lands along the Babocomari River by selling development rights and placing conservation easements on the land. The land on the Research Ranch is already protected from development.

Introduction

The Babocomari River is a major tributary of the San Pedro River in Santa Cruz and Cochise counties, Arizona. This 310 square mile catchment includes rolling grasslands on the Sonoita plain, Chihuahuan desert scrub of the Whetstone pediment, oak woodlands in the Canelo Hills and the pine-oak forests of the northwestern Huachuca Mountains. The Babocomari River runs for 25 miles from its headwaters near Sonoita at 5000 feet elevation, eastward to join the San Pedro at Fairbanks at an elevation of 3850 feet (Cook and others 2009). This important tributary contributes about 6000 acre feet of water annually to the San Pedro River system (ADWR, 2005). Protection and monitoring of the Babocomari River and associated ecosystems are an important part of the management of water resources in the area. The Arizona Department of Water Resources funded a 5-year

study with a grant (09-164WPF) in 2009. Monitoring transects were installed in 2009 and 2010 and will be re-read each year through 2013.

The objectives of the grant are (1) construct 2 miles of fence to restrict access by livestock to the Babocomari River corridor; (2a) install six vegetation and geomorphic transects on riparian grasslands (sacaton); (2b) install six riparian vegetation and geomorphic monitoring transects; (3) present annual results to the participating ranch properties for use in making management decisions. This paper addresses objectives 2a and 2b.

Methods and Results

Riparian Grasslands (Sacaton)

Large bottomlands of giant sacaton (*Sporobolus Wrightii* Monro ex Scribn) are found on both ranches. Six riparian grassland monitoring sites were established in the autumn of 2009 and were re-surveyed for canopy and basal cover by vegetative species in 2010 and 2011. Transects are re-surveyed for changes in channel morphology annually.

We present data from one riparian grassland (sacaton) transect as an example.

Transect # 1 is on the ARR just below the confluence of Post Canyon and O'Donnell Canyon and was established by Dr. Ron Tiller in 1997. A rain gauge is within 600 meters and a piezometer (7 m deep well) nearby is read quarterly for depth to groundwater. This transect

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is 448.5 meters long. The southern half of the cross section burned in the Canelo fire (wildfire) on May 6, 2009. Everything north of the Post/O'Donnell Canyon channel was unburned. Ten, 100-meter lines were re-sampled for vegetative cover by species and soil cover at fixed stations along this transect.

Precipitation in 2011 (13 inches) was much lower than in 2010 (21.5 inches) and was only 75% of the long-term average. Total perennial grass foliar cover on this transect was 43% with 7% basal cover, down slightly from 2010 with giant sacaton dominating. Vine mesquite (*Hopia obtusa*), blue grama (*Bouteloua gracilis*), green sprangletop (*Leptochloa dubia*) and sideoats grama (*Bouteloua curtipendula*) made up the remainder of the cover. Basal cover of litter was higher and bare soil lower in 2011, although the differences are within sampling error. Annual forb cover was less in 2011 due to a "La Nina" winter and very poor winter-spring moisture. (figs. 1, 2).

Riparian Stream

Monitoring stations were established in May of 2010 at three locations along the Babocomari River below the ranch headquarters. They were re-read in June 2011. Data from one monitoring station is included as an example.

BR #1 is on the Babocomari River and begins about 100 meters downstream of the USGS stream gauge (#09471380), about 4 miles east of the Ranch headquarters. It runs from the southwest to northeast. This portion of the Babocomari River was fenced to make a separate (River) pasture in 1996 and has been managed by grazing only during the winter months and for short periods of time (2 to 3 weeks) since then. The pasture was not grazed in either 2009 or 2010.

The monitoring at this location consists of a cluster of three riparian green-line transects for herbaceous vegetation paired with three belt transects (3 m wide) on both banks to record tree species by canopy

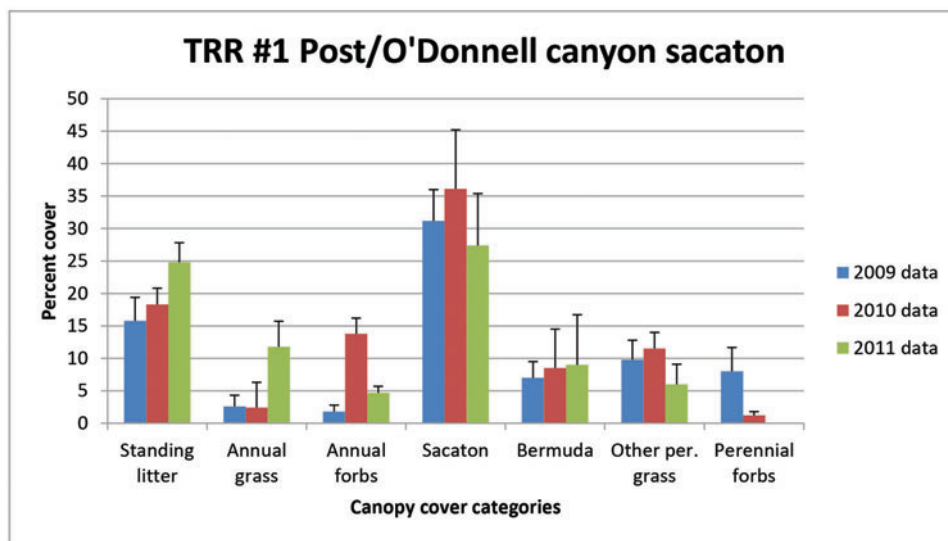


Figure 1—Percent canopy cover for TRR #1.

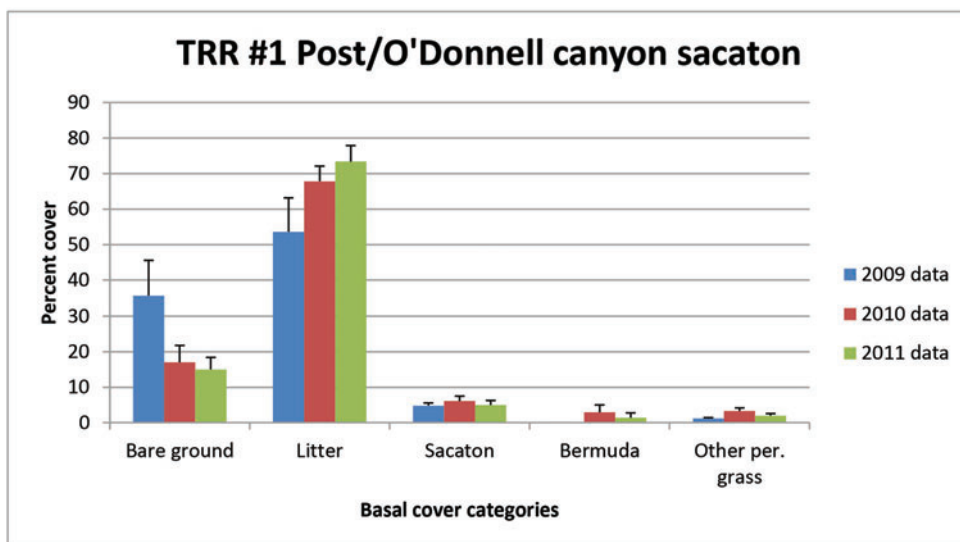


Figure 2—Percent basal cover for TRR #1.

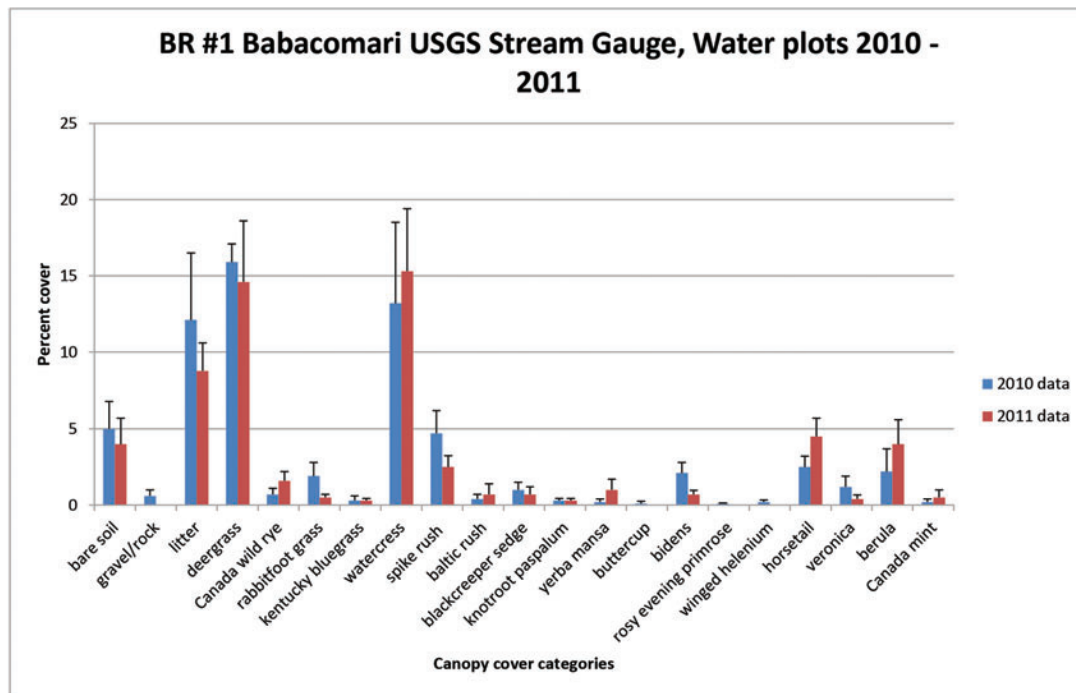


Figure 3—Percent canopy cover for BR #1.

cover. Green-line transects (Medina 2008) are 40 m in length along both banks. This technique helps segregate the plant community into bank loving and water loving species. Data are presented separately for bank plots and water plots. Herbaceous vegetative data are presented as average canopy cover by species summed for all three transects in a cluster. Tree vegetative data are presented as average canopy cover by species and average total canopy cover for the transect area. Total cover is often less than the sum of individual tree species cover because individual tree canopies overlap.

Geomorphic monitoring includes three survey cross sections, one perpendicular to the stream channel at the midpoint of each transect in the cluster.

The vegetative data show a diverse plant community dominated by native wetland species. Deergrass (*Muhlenbergia rigens*) dominates the bank plots with lesser amounts of horsetail (*Equisetum laevigatum*) and spike rush (*Eleocharis palustris*) (fig. 3).

Deergrass and watercress (*Rorippa nasturtium-aquaticum*) dominate the water plots with lesser amounts of spike rush, horsetail, and several important aquatic forbs. Banks are extremely well vegetated with only 4 to 5 % bare (exposed) soil. There were no significant changes in the understory plant community from 2010 to 2011. Total tree canopy cover averaged over all three transects is 63%. Cottonwood (*Populus fremontii*) is dominant and Gooding willow (*Salix goddingii*) is sub-dominant. There were no significant changes in tree canopy from 2010 to 2011.

Geomorphic cross sections were surveyed at 2- to 3-meter intervals and perpendicular to the stream at each transect. Cross sections spanned the floodplain and low stream terraces on either side. Re-survey of the cross sections show little change in the last 3 years.

Conclusions

Monitoring information developed during this study is being used to help make management decisions that maintain and improve vegetative conditions along the Babocomari River, several major tributaries, and the Babocomari Cienega. Both the BR and ARR management intend to continue monitoring at these sites after this WPF grant expires. The water, plant, and animal resources of this system are diverse and rarely found intact with such good environmental and hydrologic conditions. In addition to this monitoring effort, the BRR has begun to place conservation easements on the land. The land on the ARR is already protected from development. The Babocomari River and its upper watershed are worth preserving and protecting for generations to come.

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Important Bird Areas of the Madrean Archipelago: A Conservation Strategy for Avian Communities

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Abstract—The Important Bird Areas (IBA) Program is a worldwide program through BirdLife International that identifies sites considered to provide important habitats for avian species. Criteria for designation are species abundance, diversity, and range restriction. As the United States Partner of BirdLife International, the National Audubon Society administers the IBA Program in the United States. In Mexico, the network of AICAs is administered by CONABIO. The Madrean Archipelago has a diverse range of Identified IBAs (AICAs, *Áreas de Importancia para la Conservación de las Aves*, in Mexico) that feature riparian, wetland, grassland, and Madrean oak woodland habitats. Five of the 24 IBAs and three of the AICAs in the region are globally significant: the Chiricahua Mountains, San Pedro Riparian National Conservation Area, Whitewater Draw State Wildlife Area, and Willcox Playa.

Introduction

The purpose of designation as an IBA is highlighting the value of specific sites. The lower elevation riparian IBAs are vital for neotropical migrants in the spring as well as providing habitat for resident species. In these habitats, which are particularly productive in the spring, these species can refuel and rest before continuing on their journey north to breeding grounds. The high elevation “Sky Island” IBAs are very productive in the fall and serve as vital stop-over points for migrants headed south. Many birds complete their interrupted molt in these IBAs. This network serves to identify those habitats most important to conserve to benefit native birds.

Important Bird Areas

Bird Conservation Region 34: Sierra Madre Occidental-Sonoran Joint Venture

The Sierra Madre Occidental “Sky Islands” and associated grasslands and riparian corridors are a shared ecological system with Arizona and New Mexico, USA and Sonora, Mexico. The biological diversity of this region is well described and includes significant sites in Arizona such as the Chiricahua and Huachuca Mountains, the San Pedro River, and the San Rafael Grasslands. The National Audubon Society Appleton-Whittell Research Ranch is located within the grasslands and Madrean oak woodland communities. The headwaters of the San

Pedro River and the southern portion of the San Rafael grasslands are in Sonora, Mexico, where the continuation of the mountain Sky Islands provides a connection south into the sub-tropical regions of the Sierra Madre Occidental.

Among the species whose range extends into the United States in this region, highest priorities include Mexican Spotted Owl, Eared Quetzal, Lucy’s Warbler, Red-faced Warbler, Strickland’s (Arizona) Woodpecker, and Montezuma Quail. Riparian areas in lowlands support many in-transit migrants as well as breeding Thick-billed Kingbirds, Bell’s Vireo, and Western Yellow-billed Cuckoos.

Identification of Mexico AICAs in northern Sonora and United States IBAs within the Apache Highlands ecoregion as a globally significant International IBA/AICA management zone will serve as a unifying statement of shared birds and habitats. An International and global AICA/IBA is supported by the Sonoran Joint Venture and Audubon as a contributing strategy to promote conservation of shared border birds.

Sistema de Islas Sierra Madre Occidental/ Sierra Madrean Sky Islands

Globally Important Species

Strix occidentalis Spotted Owl (USA and Mexico)

Euptilotis neoxenus Eared Quetzal (Mexico)

Vireo bellii Bells’ Vireo (USA and Mexico) Riparian

Calcarius ornatus Chestnut-collared Longspur (winter) (USA and Mexico) grasslands

Global Biodiversity—Assemblage of Biome-restricted species

Continental Important Species

Cyrtonyx montezumae Montezuma Quail

Picoides stricklandi Arizona Woodpecker

Coccyzus americanus Western Yellow-billed Cuckoo

Asio flammeus Short-eared Owl (Winter)

Otus trichopsis Whiskered Screech Owl

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Micrathene whitneyi Elf Owl
Caprimulgus ridgwayi Buff-collared Nightjar
Lampornis clemenciae Blue-throated Hummingbird
Calypte costae Costa's Hummingbird
Melanerpes lewis Lewis's Woodpecker (winter)
Colaptes chrysoides Gilded Flicker
Tyrannus crassirostris Thick-billed Kingbird
Vermivora luciae Lucy's Warbler
Dendroica graciae Grace's Warbler
Cardellina rubrifrons Red-faced Warbler
Pipilo aberti Abert's Towhee
Aimophila carpalis Rufous-winged Sparrow
Aimophila quinquestriata Five-striped Sparrow
Calcarius mccownii McCown's Longspur (Winter)
Spizella breweri Brewer's Sparrow (Winter)
Spizella atrogularis Black-chinned Sparrow
Anmodramus bairdii Baird's Sparrow

Species of Conservation Concern

Callipepla squamata Scaled Quail

Arizona Important Bird Areas

Appleton-Whittell Audubon Research Ranch—National Audubon, BLM, Coronado National Forest-Grasslands

Globally important bird species: Montezuma Quail

Chestnut-collared Longspur and McCown's Longspur (winter)

Buenos Aires National Wildlife Refuge—U.S. Fish and Wildlife Service

Globally important bird species: Masked Bobwhite Quail

California Gulch—Coronado National Forest

Globally important bird species: Five-striped Sparrow, Spotted Owl
 Chiricahua Mountains—Coronado National Forest

Globally important bird species: Spotted Owl, Whiskered Screech-Owl, Violet-crowned Hummingbird, Arizona Woodpecker, Sulphur-bellied Flycatcher, Buff-breasted Flycatcher, Grace's Warbler and Mexican Chickadee

Huachuca Mountains—Coronado National Forest

Globally important bird species: Spotted Owl

Santa Cruz River—Arizona State Park, U.S. Park Service

Globally important bird species: Bell's Vireo

San Pedro River Riparian National Conservation Area—Bureau of Land Management

Globally important bird species: Bell's Vireo

San Rafael Valley—Coronado National Forest, Arizona State Parks

Globally important bird species: Chestnut-collared Longspur (winter), McCown's Longspur (winter)

Santa Rita Mountains—Coronado National Forest

Globally important bird species: Spotted Owl

Sonoita Creek—The Nature Conservancy and Arizona State Park

Globally important bird species: Bell's Vireo

Sycamore Canyon—Coronado National Forest

Globally important bird species: Five-striped Sparrow, Spotted Owl, Buff-collared Nightjar

Whitewater Draw State Wildlife Area—Arizona Game and Fish

Globally important bird species: Sandhill Crane

Potential Arizona Important Bird Areas:

Patagonia Mountains and Pinaleno Mountains—Coronado National Forest

Globally important bird species: Spotted Owl

Las Cienegas National Conservation Area—Bureau of Land Management

Rufous-winged Sparrow

New Mexico Important Bird Areas:

Clanton Canyon—Coronado National Forest

Montezuma Quail, Whiskered Screech-Owl, Arizona Woodpecker, Whip-poor-will, Elf Owl, Dusky-capped Flycatcher, Grace's Warbler

Gray Ranch Grasslands—Animas Foundation

Botteri's Sparrow

Guadalupe Canyon – Bureau of Land Management

Costa's, Broad-billed, Blue-throated, Magnificent, and Violet-crowned Hummingbird, Northern Beardless-Tyrannulet, Thick-billed Kingbird, and Varied Bunting.

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Appendix: Migratory Birds of Conservation Focus

Map sources: Birds of North America; Cornell Laboratory of Ornithology: green = winter; dark tan = breeding; light tan = migration; blue = yearlong.

Gray Hawk *Asturina nitida*



Common Black-Hawk *Buteogallus anthracinus*. Mexico has resident populations (in the South) and migratory (in the north).



Elf owl *Micrathene whitneyi*



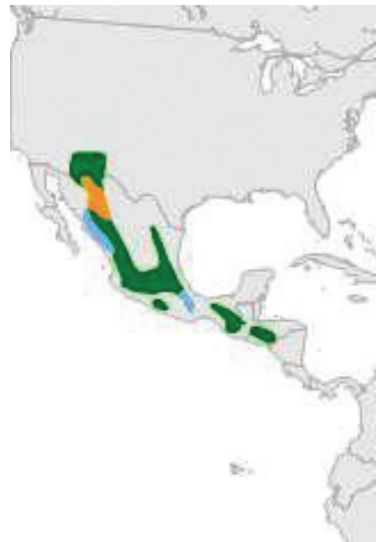
Mexican whip-or-will *Caprimulgus vociferous*



Thick-billed kingbird *Tyrannus crassirostris*



Buff-breasted flycatcher *Empidonax fulvirostris*



Broad-billed Hummingbird

Cyanthus latirostris



LEGEND

- Year Round
- Summer (breeding)
- Winter (non-breeding)
- Migration

Map by Cornell Lab of Ornithology
Range data by NatureServe

Blue-throated Hummingbird

Lampornis clemenciae



LEGEND

- Year Round
- Summer (breeding)
- Winter (non-breeding)
- Migration

Map by Cornell Lab of Ornithology
Range data by NatureServe

Magnificent Hummingbird

Eugenes fulgens



LEGEND

- Year Round
- Summer (breeding)
- Winter (non-breeding)
- Migration

Map by Cornell Lab of Ornithology
Range data by NatureServe

Lucifer Hummingbird

Calothorax lucifer



LEGEND

- Year Round
- Summer (breeding)
- Winter (non-breeding)
- Migration

Map by Cornell Lab of Ornithology
Range data by NatureServe

Costa's Hummingbird *Calypte costae*



Map by Cornell Lab of Ornithology
Range data by NatureServe

Rose-throated becard *Pachyrhamphus aglaiae*



Northern Beardless tyrannulet *Camptostoma imberbe*



Olive warbler *Peucedramus taeniatus*



Lucy's warbler *Vermivora luciae*



Grace's Warbler *Dendroica graciae*



Red-faced warbler *Cardellina rubrifrons*



Five-striped sparrow *Aimophila quinquestriata*



Varied bunting *Passerina versicolor*



Botteri's sparrow *Aimophila botteri*



Baird's sparrow *Ammodramus bairdi*



McCowan's longspur *Calcarius mccownii*
(winter) (winte



Chestnut-collared longspur *Calcarius ornatus*



Lark bunting *Calamospiza melanocorys* (win-
ter) (winter)



The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented herein.

Preliminary Flora of Ojo de Agua Tonibabi, Sierra La Madera, Sonora, Mexico

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Abstract—Ejido Tonibabi is located 12 kilometers east-northeast of Moctezuma in east-central Sonora, México (29°50'16"N 109°33'45"W, 780 m elevation). The vegetation is riparian in the wetlands and foothills thornscrub on slopes. The flora was inventoried on transects in different areas in Ejido Tonibabi. Specimens were collected to identify by comparing with specimens in the University of Arizona and Universidad de Sonora Herbaria and for voucher specimens. A total of 162 species in 125 genera and 47 families were documented in the area. The families with the most species were Fabaceae, Asteraceae, Euphorbiaceae, Convolvulaceae, Poaceae and Cactaceae, which contain 53.1% of the flora. The most important life form was annual herbs (47 taxa), followed by perennial herbs (40 taxa), trees (21 taxa), shrubs (15 taxa), succulents (10 taxa), grasses (9 taxa), subshrubs (9 taxa), vines (8 taxa) and aquatic herbs (3 taxa). The Tonibabi flora contains 4.4% of the state flora.

Introduction

Sierra La Madera is a Sky Island mountain range located in the transition between the New World tropics and the northern temperate zone at about 29°N in east-central Sonora, which enhances the diversity of flora and fauna. Complex topography and an elevational range of ca. 1685 m (from 615 m along Río Bavispe at Huásabas to over 2300 m on the highest peak) result in diverse habitats in the Sierra la Madera. The Ojo de Agua Tonibabi is in the southwestern foothills of the Sierra la Madera in east-central Sonora, México. There are no published floras in foothills thornscrub in Sonora. Yanes-Arvayo and others (2011) present a photographic guide to the common plants of the Sierra La Madera. We report a preliminary flora of the Tonibabi area, and compare it with the flora of the Río Bavispe region in northeastern Sonora (White 1948) in this paper.

Study Area

The Ojo de Agua Tonibabi (29°50'16"N, 109°33'45"W, 780 m elevation) is in the Ejido Tonibabi 12 kilometers east-northeast of Moctezuma in the Municipio (= County) de Moctezuma in east-central Sonora, México. Soils are very thin soil and near the wet areas saline, which indicates that groundwater is near the surface. The vegetation

in the Tonibabi study area is willow (*Salix gooddingii*) and mesquite (*Prosopis velutina*) in riparian areas along streams and foothills thornscrub on slopes. Foothills thornscrub is a tropical shrub-tree formation that occurs in a broad transition between the Sonoran Desert to the west and tropical deciduous forest or oak woodland in the Sierra Madre Occidental to the east (Búrquez and others 1999; Martínez-Yrizar and others 2010).

Methods

Selected sites with the highest concentration of plants in the Tonibabi area were visited on eight field trips between April and December 2011. Plants were collected and observed in lowland riparian habitats near streams, and on rocky slopes and disturbed roadsides. Plant collections were identified using floristic references and comparison with specimens in the University of Arizona and Universidad de Sonora (USON) herbaria. Online resources consulted were the University of Arizona herbarium (<http://ag.arizona.edu/herbarium/>), the Madrean Archipelago Biodiversity Assessment (MABA) (<http://www.madrean.org>), and the United States Department of Agriculture Plants (<http://plants.usda.gov>) databases. Voucher specimens were deposited into USON. Plant collections and images in this study are available in the MABA database.

Results

A total of 162 plant species in 125 genera and 47 families were identified in the Tonibabi area. The families with the most species were Fabaceae (27 species, 16.7%), Asteraceae (20 species, 12.3%), Euphorbiaceae (12 species, 7.4%), Cactaceae (10 species, 6.2%), Poaceae (9 species, 5.6%), and Convolvulaceae (8 species, 4.9%; fig. 1). These families contained 86 species in 60 genera and 86 species

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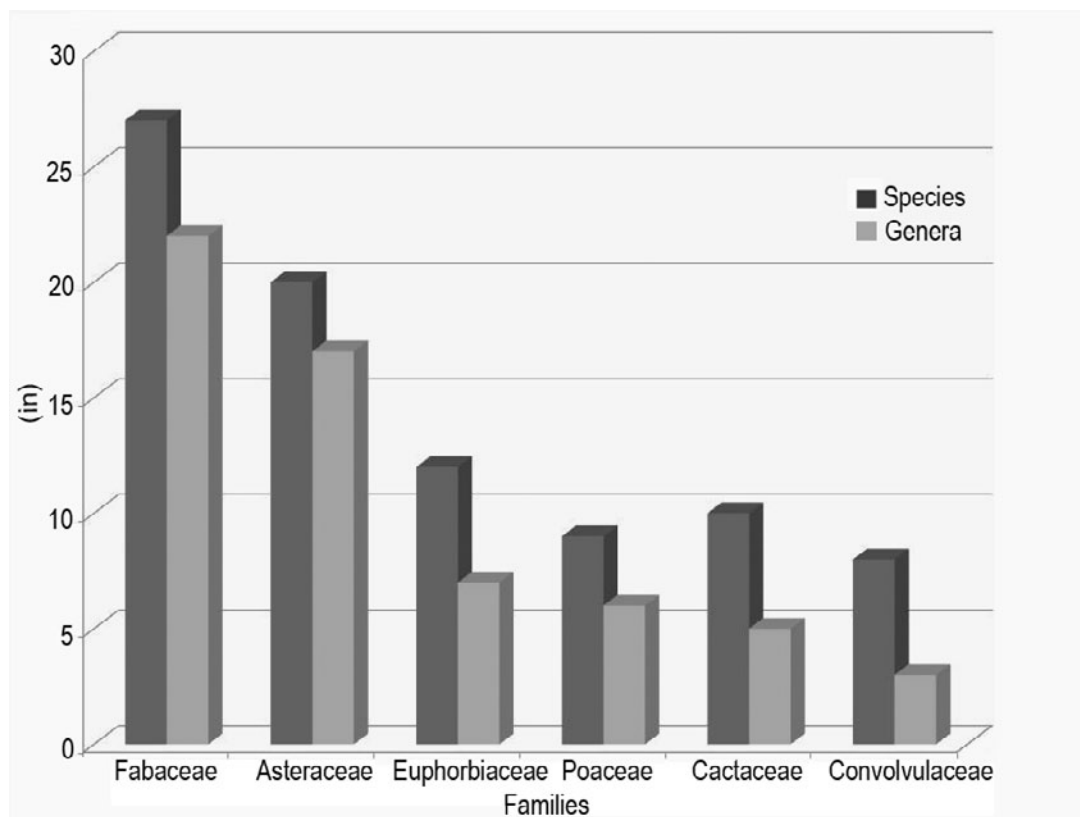


Figure 1—Species and genera in the most important families in the Tonibabi flora.

(53.1% of the flora). The genera with the most species were *Acacia*, *Boerhavia*, *Bouteloua*, *Bursera*, *Desmodium*, *Euphorbia*, *Ipomoea*, *Jatropha*, *Opuntia*, and *Portulaca* with 19.5% of the total species.

The most important life forms in Tonibabi are herbs and trees (66.7% of the flora), followed by cacti and grasses (11.7% each), shrubs (9.5%), subshrubs (5.5%), vines (4.9%) and aquatic herbs (1.8%). Riparian species are Goodding willow (*Salix gooddingii*), mesquite (*Prosopis velutina*), tésota (*Acacia occidentalis*), batamote (*Baccharis salicifolia*), cadillo (*Xanthium strumarium*), and *Mimulus guttatus*. *Matelea pringlei* and *Tragia jonesii* are regional endemic species only found in Sonora. *Pseudabutilon thurberi* also occurs in adjacent Arizona. *Amoreuxia palmatifida* and *Olneya tesota* have a PR (Protected) status under NOM-059-SEMARNAT-2010. Only four species in the Tonibabi flora (2.5%) were non-native plants: *Nasturtium officinale*, *Nicotiana glauca*, *Melinis repens* and *Penisetum ciliare* (Van Devender and others 2009).

Discussion

The State of Sonora has a diverse flora with 3483 species (3237 natives) including 104 varieties, 43 subspecies, and 30 interspecific hybrids. Only 78 taxa (68 species, 8 subspecies, and 2 varieties) are endemic to mainland Sonora (Van Devender and others 2010). The Tonibabi flora has widespread riparian/wetlands species and typical tropical foothills thornscrub species. As in many floras, herbs are numerically dominant in the flora, with relatively few trees, shrubs and large succulents such as *Bursera fagaroides*, *B. laxiflora*, *Mimosa*

distachya, *Lysiloma divaricatum*, *Jatropha cordata*, and *Stenocereus thurberi*, structural dominants in the vegetation. Trees with 21 species are only 13% of the flora.

Stephen S. White from the University of Michigan led expeditions to study the flora of the Río Bavispe Region in northeastern Sonora from 1938 to 1941 (White 1948). He collected in a wide range of habitats in the region, resulting in 1200 species (currently 995 taxa after revision) in 549 genera in 114 families. In July 1938, he collected in the Moctezuma area including eleven specimens at Tonibabi. *Eustoma exaltatum*, *Martynia althaeifolia*, *Phaulothamnus spinescens*, and *Samolus valerandi* ssp. *parviflorus* were not found in the present study. Catchfly prairie gentian (*E. exaltatum*) is an herb with showy lavender flowers found in seeps and springs and is rare in Sonora. Only 76 species (47%) in the Tonibabi flora are shared with the Río Bavispe flora, reflecting White's brief visit to the area, and that foothills thornscrub is only found in the Río Bavispe Region in the southern end of the Sierra El Tigre west across the to the Sierra la Madera.

Tonibabi with its extensive wetlands is a unique area in foothills thornscrub. Large areas of whitish soil visible from satellite images suggest that the wetlands were much more extensive in the past. Study of pollen in the spring sediments show that the ciénega formed 8300 years ago in the early Holocene and was wetter than today until after 2300 years ago (Espinoza-Encinas 2012). Plants in the Ojo de Agua Tonibabi are disjunct from other wetlands and possibly relict populations from wetter past climates.

Acknowledgments

We thank George M. Ferguson for his careful review.

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Examining Wildlife Responses to Phenology and Wildfire Using a Landscape-Scale Camera Trap Network

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Abstract—Between 2001 and 2009, the Borderlands Jaguar Detection Project deployed 174 camera traps in the mountains of southern Arizona to record jaguar activity. In addition to jaguars, the motion-activated cameras, placed along known wildlife travel routes, recorded occurrences of ~ 20 other animal species. We examined temporal relationships of white-tailed deer (*Odocoileus virginianus*) and javelina (*Pecari tajacu*) to landscape phenology (as measured by monthly Normalized Difference Vegetation Index data) and the timing of wildfire (Alambre Fire of 2007). Mixed model analyses suggest that temporal dynamics of these two species were related to vegetation phenology and natural disturbance in the Sky Island region, information important for wildlife managers faced with uncertainty regarding changing climate and disturbance regimes.

Introduction

The Madrean Archipelago is known to have exceptional wildlife diversity, related in part to the wide variety of available habitat in the area as well as its location at the confluence of ranges of subtropical and northern species (Felger and Wilson 1994). Monitoring wildlife populations in this area has become increasingly important as human-caused and natural disturbances (e.g. United States/Mexico Border fence, drought and climate change) affect wildlife movement corridors and the quality and quantity of available habitat. Populations of terrestrial vertebrates, both herbivores and predators, are dependent on primary productivity of vegetation for their survival, and fluctuate according to resource availability (White 2008). This dynamic is often amplified in arid and semi-arid ecosystems where populations respond to resource pulses, in particular growth of vegetation, driven by both local and global climatic patterns (Marshall and others 2002). Vegetation dynamics, which include plant phenology, are captured and quantified by satellite imagery and have been used to model wildlife habitat, vegetation cover, and species abundance (Wallace 2008; Sesnie and others 2011). In addition to climate-induced variability in plant productivity, resource availability for mammals can also be limited or enhanced by natural disturbances like wildfire (Smith 2000). For

example, ungulates are responsive to changes in vegetation structure, feeding in areas with increased plant growth after high-intensity fires, and carnivores and omnivores are believed to be opportunistic and will often feed near areas of recent burns where prey abundance has increased (Smith 2000).

Monitoring wildlife populations is traditionally accomplished using labor-intensive human observation (e.g. avian surveys) or expensive trapping methods (e.g. capture-recapture). An alternative to human observation and trapping are remote, motion-triggered camera “traps.” Camera traps are typically set up to capture information on rare and secretive species of conservation concern (McCain and Childs 2008), but are increasingly being used to monitor general wildlife population dynamics (Rowcliffe and Carbone 2008). Motion-triggered cameras offer several benefits over traditional methods of wildlife observation (see Cutler and Swann 1999); they are noninvasive, can be set up in rugged and remote locations, and provide continuous monitoring while the camera remains operational. This last point is an important distinction in that repeat, long-term camera monitoring provides a photographic time series that can be analyzed with continually collected satellite and climate data allowing us to examine connections between wildlife abundance and vegetation phenology.

In this project, we used an existing, landscape-scale camera trap network to examine the relationship between wildlife dynamics, vegetation phenology, and fire. We chose two example species, white-tailed deer (*Odocoileus virginianus*) and javelina (*Pecari tajacu*), which are the primary prey of the jaguar and other felids as well as economically important game species in Arizona. It was anticipated that the multi-species information gathered from the photographic database might provide insight into decadal and annual population dynamics, by capturing a measure of wildlife abundance at the camera locations as well as activity in the movement corridors on which the cameras were located. In addition, this study was conceived to help

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guide future trap efforts and study design by demonstrating the value of incidental, non-targeted species data for understanding wildlife dynamics related to climate and vegetation, and illustrating some of the challenges of data analysis at a landscape scale.

Study Area

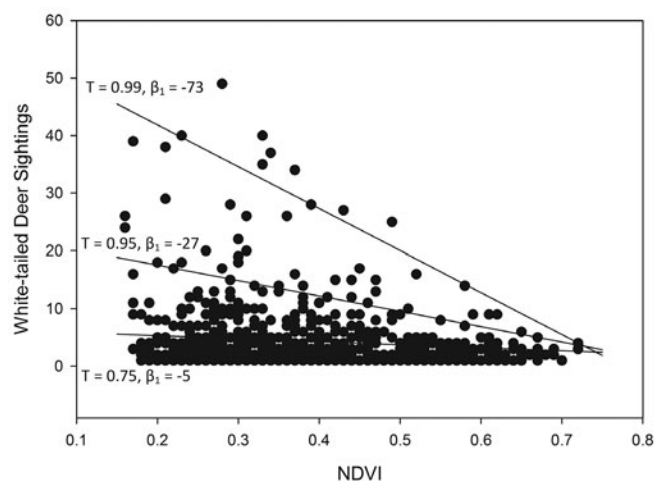
The study area is located at the western portion of the Madrean Archipelago north of the United States/Mexico border stretching from the Altar Valley to the San Rafael Valley (McCain and Childs 2008). Wildlife monitoring sites were located at the Baboquivari, Sierrita, Tumacácori, Atascosa, Patagonia, and Santa Rita Mountains. Vegetation of the study sites consists of Madrean evergreen woodland and semidesert scrub grassland (Brown 1994) and elevations range from 934-1944 m. The average maximum temperature recorded at Tumacácori National Historical Park (1948-2005) was 36 °C, (July), the average minimum was 0 °C (January), and average annual precipitation was 40 cm.

Data and Methods

Primary data for this project were (1) animal detections collected by the Borderlands Jaguar Detection Project (McCain and Childs 2008) using a series of remote cameras and (2) 250-meter resolution Normalized Difference Vegetation Index (NDVI) data. The following sections provide details of the camera and vegetation data sets.

Camera Trap Data

A total of 8 (174 total cameras) different camera sites were monitored between 2001 and 2009 using passive infrared camera systems that detect heat-in-motion. Cameras were intentionally located in areas with high probability of detecting jaguar movement (i.e. game trails, washes, and canyon bottoms). Cameras were typically left in the original location for the entire length of the study in order to detect variations in movement over time; however, some cameras were moved to more strategic nearby sites if higher animal activity was found in the area.



Moderate Resolution NDVI

We used Normalized Difference Vegetation Index (NDVI) calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) data. Composites of MODIS NDVI data were acquired from the University of Arizona Remote Sensing Center for 2000-2009. NDVI is calculated using a ratio of the spectral properties of vegetation reflectance in the red and near-infrared wavelengths of the electromagnetic spectrum; green vegetation typically has low reflectance in red wavelengths and high reflectance in the near-infrared wavelengths. NDVI values are positively correlated with the relative abundance of green, growing vegetation.

Analysis

Detection photographs were compiled into a digital database with each camera location attributed with the number of animal sightings per month by species, monthly NDVI, and time-since-fire values (months) for cameras that were in or near the Alambre burn perimeter (July 7, 2007 in the Baboquivari Mountains).

Counts of animal sightings per month were analyzed and histograms of whitetail sightings were constructed by mountain range (8 total). The relationship of whitetail sightings with NDVI among mountain ranges was evaluated with quantile regression. Additionally, a mixed model analysis was performed with whitetail sightings as the response, mountain range, month, and NDVI as fixed effects, and year and camera as random effects. The relationship of javelina sightings with NDVI near the Alambre burn perimeter was evaluated using a mixed model analysis with NDVI as a fixed effect and year and camera as random effects. The relationship of javelina sightings with months since fire was similarly evaluated with the time variable as a fixed effect and year and camera as random effects.

Results and Discussion

Monthly sightings of whitetail ranged from very low to as large as 50 in the different mountain ranges. Two-tailed Student's t-tests show that camera locations with whitetail sightings have significantly lower NDVI values than camera locations with no sightings (fig. 1).

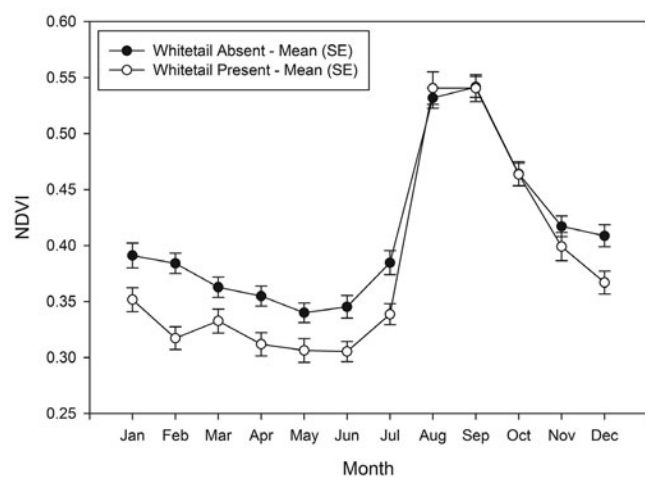


Figure 1—Quantile regression results for monthly white-tailed deer sightings as a function of NDVI. Tau (T) refers to the quantile of whitetail sightings conditional to NDVI, and β_1 values are the slopes of the regression lines, which were significant with $p < 0.05$ (left). Mean (standard error) monthly NDVI for camera locations with Whitetail deer sightings during the study period (right).

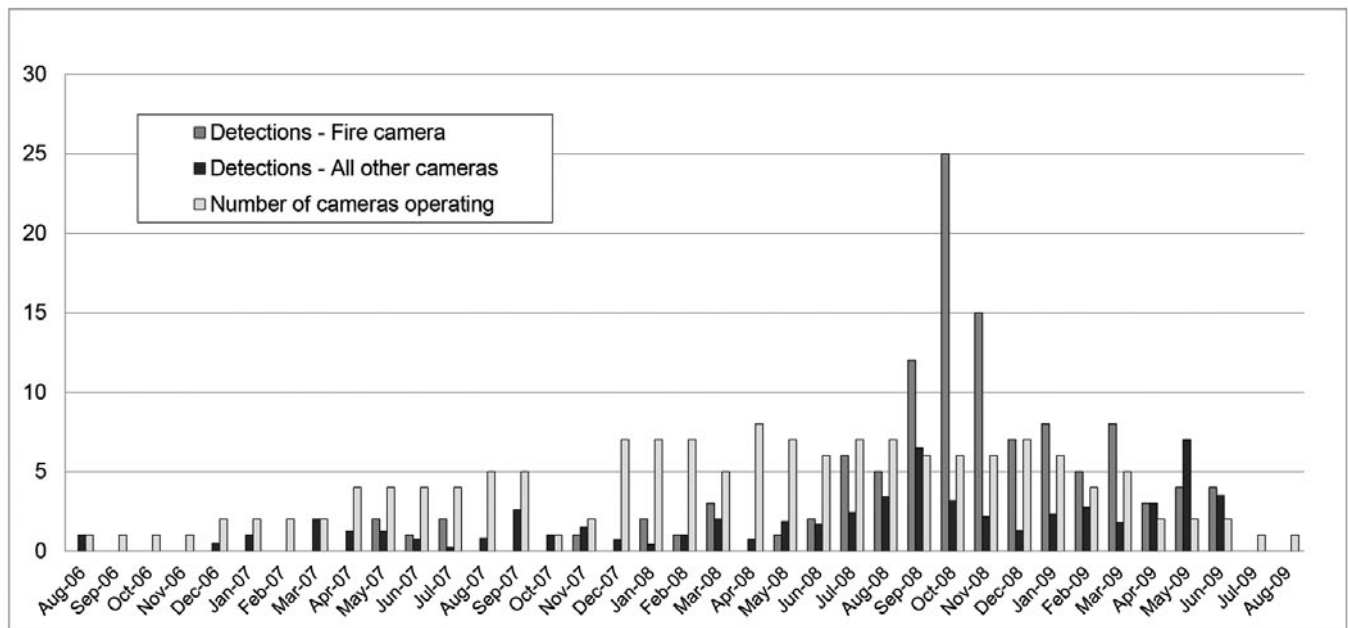


Figure 2—Distribution of javelina sightings at the Coyote Mountain study site before and after the Alambre Fire of July 7, 2007. One camera located inside the burn perimeter showed a marked increase in javelina sightings in 2008 when compared to cameras outside the burn area.

Mixed model analysis indicated that mountain range ($p = 0.1$) and NDVI ($p = 0.06$) had a weakly moderately significant correlation with whitetail sightings, whereas month did not appear to be significant ($p = 0.27$). Quantile regression analysis showed a significant negative relationship for the largest values of whitetail sightings conditional to NDVI (fig. 1). This suggests that low abundance of whitetail sightings occurred for a wide range of NDVI; however, the largest monthly sightings occurred during periods of relatively low NDVI. On average, large values of NDVI occurred during the summer monsoon and post-monsoon months of August, September, and October (fig. 2) and NDVI was comparably lower during the other months of the year when sightings were greater. This observed pattern may be related to greater whitetail activity during the breeding season (winter months).

Mixed model analyses indicated that NDVI and time since fire were significant for javelina sightings ($p = 0.02$, respectively). Javelina sightings increased with time (1–24 months) since burning. The relationship of javelina sightings to NDVI was also positive. NDVI often decreases immediately after fire, then increases with time as vegetation recovers, and therefore might be expected to covary with time since burning; however, histograms depicting observations from a camera in the fire perimeter compared to those outside suggest that the increase of javelina was related to post-fire effects (fig. 2).

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Mapping Landscape Phenology Preference of Yellow-Billed Cuckoo With AVHRR Data

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Abstract—We mapped habitat for threatened Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) in the State of Arizona using the temporal greenness dynamics of the landscape, or the landscape phenology. Landscape phenometrics were derived from Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) data for 1998 and 1999 by using Fourier harmonic analysis to analyze the waveform of the annual NDVI profile at each pixel. We modeled the spatial distribution of Yellow-billed Cuckoo habitat by coupling the field data of Cuckoo presence or absence and point-based samples of riparian and cottonwood-willow vegetation types with satellite phenometrics for 1998. Models were validated using field and satellite data collected in 1999. The results indicate that Yellow-billed Cuckoo occupy locations within their preferred habitat that exhibit peak greenness after the start of the summer monsoon and are greener and more dynamic than “average” habitat. Identification of preferred phenotypes within recognized habitat areas can be used to refine habitat models, inform predictions of habitat response to climate change, and suggest adaptation strategies.

Introduction

The Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) is a neo-tropical migrant bird that travels north from Central and South America into the southwestern United States to nest during the summer. Riparian forest and woodland nesting habitat of this threatened species has declined in the western United States over the past century. As a result, Western Yellow-billed Cuckoos have been petitioned for possible listing under the 1973 Endangered Species Act.

Riparian habitats contain dense, water-loving deciduous species including cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*)—vegetation preferred by Yellow-billed Cuckoo. In central and southern Arizona, there is a marked contrast between the riparian vegetation and the surrounding arid and semi-arid upland vegetation that dominates most of the landscape. This contrast produces strong vegetation reflectance signals that can be detected by satellite remote sensing both in terms of the strength of the signal due to the difference in vegetation type and density and also in terms of the temporal pattern of the greenness dynamics, or landscape phenology.

The objectives of this study were to identify characteristic phenology patterns preferred by Yellow-billed Cuckoo as captured by satellite data and use these characteristics to map preferred habitat of the Yellow-billed Cuckoo in the State of Arizona.

Data

The Yellow-billed Cuckoo field data used in the models came from a state-wide census (Johnson and others 2010). The satellite data used are the Advanced Very High Resolution Radiometer (AVHRR) 1-kilometer resolution Normalized Difference Vegetation Index (NDVI) bi-weekly composites. These data are sensitive to biophysical vegetation characteristics, including biomass and percent cover (Huete and others 2002). The riparian vegetation map was created by the Arizona Game & Fish Department (AZGF) in 1994 (www.land.state.az.us). For this study, we created two binary images: all riparian (RIP) vegetation and riparian Cottonwood-Willow (CW) vegetation. We excluded any riparian vegetation in the far north and northeast of the state because no bird sightings were reported in those areas.

Methods

Five sets of point data were compiled including 78 survey locations with Yellow-billed Cuckoo present for 1998; 43 survey locations with birds absent for 1998; point-sampling polygons of CW vegetation; point-sampling polygons of RIP vegetation; and 360 bird sightings for 1999.

Phenometrics were derived by applying a Fourier harmonic analysis to the temporal AVHRR NDVI profiles at each image pixel in the State of Arizona (Jakubauskas 2001; Wallace 2002). Fourier analysis expresses a complex curve as the sum of an “additive term” and simple cosine waves of different frequencies. Three new images each representing a phenometric were created: (1) the amount of greenness—the “additive term” component that is the best fit of a flat line to the profile and is related to the vegetation productivity; (2) dynamics or variability of the greenness—the magnitude of the first frequency component that is the amplitude of the single cosine

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wave that fits the annual profile best; and (3) the timing of peak green-up—the phase of the first frequency component that is the position of the peak of the single cosine wave that fits the annual profile best, rescaled to represent a day of the year (DOY) between 0 and 365.

The phenometrics were sampled and summarized for each of the 5 point data sets. Two-tailed Student's t-tests were performed to identify the phenometrics that were significantly different in the survey locations with Cuckoos present compared to the other point locations; these phenometrics were used to create Cuckoo phenology preference models. We rescaled the phenometrics based on the statistical distribution of the values at the set of 1998 Cuckoo presence data to create uniform units of the standard deviation distance (SDD) by calculating the difference between the phenometric and the mean value observed at the 1998 Cuckoo sightings divided by the observed 1998 standard deviation.

Three models were created, one continuous and two categorical. For each model, each phenometric was stratified into three categories: “high” targeted to contain 50% of the sightings, “medium” with 30% (cumulative 80%), and “low” with 19-20% (cumulative >99%), as follows:

1. **Standard Deviation Distance-based Model**—The SDDs of selected Phenometrics were averaged to produce a phenology preference map based on the average SDD.

2. **Standard Deviation Stratified Model**—The SDD of each phenometric was stratified into three preference classes using the SDD values of +/- 0.67, +/- 1.28 and +/- 3.0; given a normal distribution, these cutoffs would capture cumulative percentages of 50, 80 and 99+, respectively. The three stratified phenometrics were then

summed, producing a single map with nine classes ranging from 1 = low preference to 9 = high preference.

3. **Rank-based Model**—The Rank and Percentile was calculated for each 1998 phenometric at the CW points. The 1998 CW ranks were identified for the phenometrics at the 50-80-99 SDD values observed at the 1998 bird sightings; these same ranks were then identified for the ranked 1999 CW phenometrics, and the corresponding 1999 phenometric values extracted. Each phenometric was stratified into three preference classes using these extracted values and the three maps were summed, producing nine classes from 1 = low preference to 9 = high preference.

The models were validated by determining how well they predicted Cuckoo presence in 1999. Refinements of the model based on observed phenometric relationships within and between years were also explored and applied.

Results

All three models created from phenometric values observed in 1998 were effective at predicting the locations of Yellow-billed Cuckoo sighted in 1999. We considered the standard deviation stratified model (fig. 1A) superior given it identified a less generalized mapping and predicts 64-98-100% cumulatively of the 1999 bird sightings in the High (greens)-Medium (orange)-Low (dark gray) classes, respectively. The model was then clipped to probable landscapes, from most to least limited with each a subset of the next (figs. 1B, C, D).

Examination of the statistics and histograms for the locations with Birds Present and the CW vegetation types shows the phenometrics

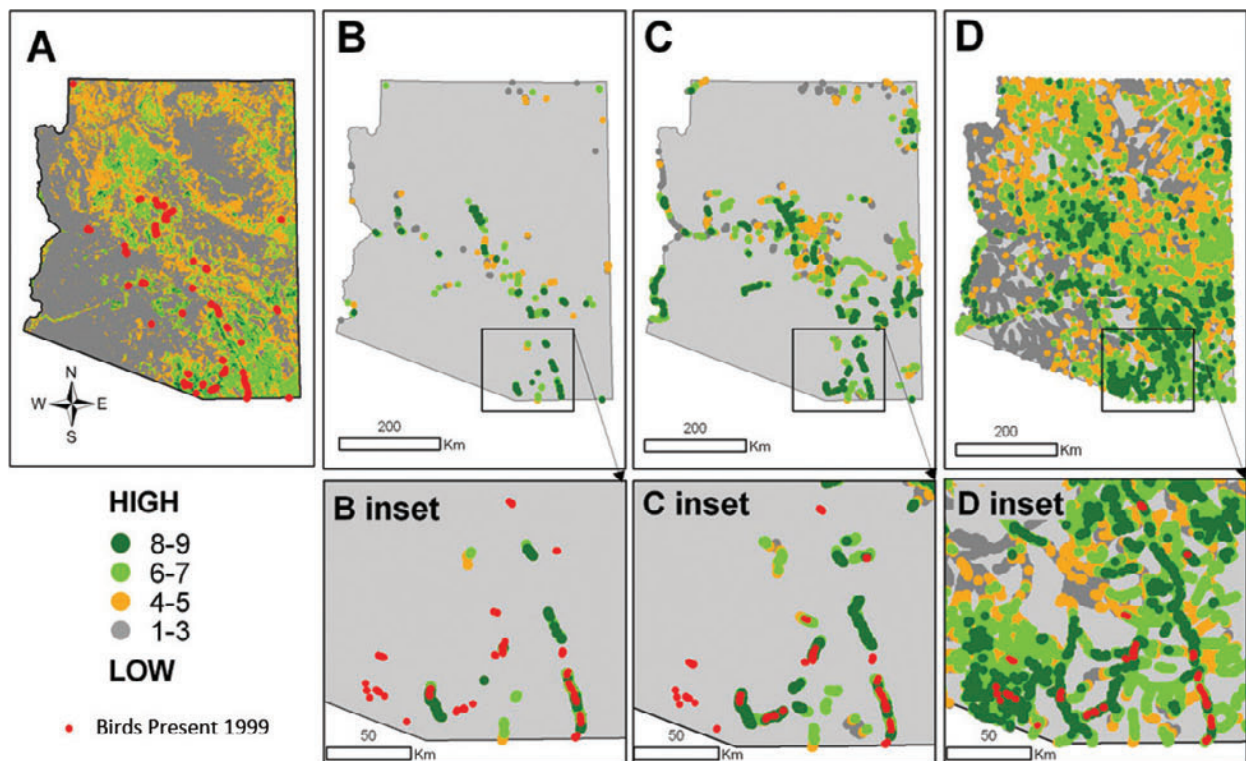


Figure 1—Standard Deviation Stratified Model, showing High-Medium-Low phenology preference classes. View B is clipped to CW vegetation, view C is clipped to RIP vegetation, and view D is clipped to the Arizona Streams Data, digitized from 1988 1:100,000 USGS topographic maps. The insets show the 1999 bird locations overlaid onto the clipped models.

of these landscapes share parallel relationships in 1998 and 1999. In both years, birds occupy landscapes that have a more variable, dynamic greenness, achieve a maximum greenness later in the year, and are significantly greener than the “average” CW vegetation. We, therefore, refined the model by averaging the observed intra-annual phenometrics offsets and created generalized models for both 1998 and 1999 that define Yellow-billed Cuckoo habitat relative to the observed phenology of the CW vegetation. These models correctly predict in High-Medium-Low classes cumulative bird presence percentages of 57-99-100 and 81-99-100, for 1998 and 1999, respectively.

Discussion

We found that Yellow-billed Cuckoo occupy locations within their preferred habitat that green up later in the year, have a more dynamic greenness and are greener than the average cottonwood-willow habitat. These could be areas of healthier and denser trees or could be a vegetation signature in the understory that reflect conditions supporting larger insects—a food that the Yellow-billed Cuckoos favor and exploit. Phenology preference models were effective at predicting Cuckoo sightings in both years, and could be refined as additional data become available. These models are successful because there is

a consistent relationship between the intra-annual phenometrics for Cuckoo sightings relative to those in their preferred cottonwood-willow habitat. It is likely that other species will exhibit similar phenotype preferences within their habitat types. Such relationships can be used to refine habitat models, predict species presence in other areas of the Southwest and better inform habitat response to climate change.

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Abstracts

Abstracts of Oral and Poster Presentations at the Conference: English and Spanish

(Some titles and authors are different from the finalized versions)

Resúmenes en Inglés y Español de las Presentaciones Orales y en Cartel del Congreso (Algunos títulos y autores son diferentes al de la versión final)

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Restoration of Ciénegas and Headwater Tributaries of the Río San Bernardino. The Cuenca Los Ojos Foundation restores lands, wetlands, and wildlife in Arizona and Sonora. This semi-arid area receives limited rainfall in a given year with extreme fluctuations, sometimes receiving up to 45% of the annual rainfall in one event. Many streams are seasonal and depending upon the watershed, can go from dry to flooding in an hour's time. Harvesting water on both slopes and drainages is therefore crucial to achieving maximum conservation outcomes. Historically, a large ciénega wetland was located where Black Draw, Hay Hollow, and Silver Creek came together to form the Río San Bernardino, just south of the International Border. The wetlands were a major stopping place for migrating birds and animals. In the early 1900's these wetlands dried due to incision of the adjacent streams. Cuenca Los Ojos has been working for more than a decade to restore these streams and adjacent upland areas. Despite historic drought conditions during the entirety of this restoration period, our work has resulted in a dramatic increase in the ciénega acreage and riparian and grassland vegetation. This in turn, has led to an increase in wildlife such as native fish, frogs, riparian and grassland bird species, and a host of mammals.

Restauración de ciénegas y afluentes de la cuenca alta del río San Bernardino. La fundación de la Cuenca los Ojos trabaja para restaurar terrenos, humedales, fauna y flora en Arizona y Sonora. Esta región semiárida tiene muy baja precipitación con una variabilidad extrema, en ocasiones recibiendo hasta el 45% de la precipitación anual en un chubasco. Muchos arroyos son temporales y dependiendo de la cuenca, pueden cambiar en una hora de secos a inundados. Así, el recolectar el agua de lluvia tanto de las laderas como de las vertientes es decisivo para lograr el máximo resultado en conservación. En el pasado un gran humedal de ciénega se ubicaba donde se juntan los afluentes Black Draw, Hay Hollow y Silver Creek para formar el río San Bernardino, justo al sur de la frontera internacional. Estos humedales fueron un importante refugio para aves y otros animales migratorios. A principios de 1900 estas ciénegas se secaron por la fragmentación causada por los arroyos adyacentes. La Cuenca los Ojos ha estado trabajando por más de una década restaurando estos arroyos y las tierras altas adyacentes. A pesar de las condiciones de sequía histórica durante estos años de restauración, hemos logrado el aumento dramático de la ciénega y la vegetación ribereña y el pastizal. Ésto a su vez a creado un aumento de fauna nativa como son: peces nativos, ranas, aves ribereñas y de pastizal y una gran variedad de mamíferos.

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Wildlife survey and monitoring in the Sky Island Region with an emphasis on Neotropical felids. The Sky Island region of southwestern U.S. and northwestern Mexico consists of isolated mountain ranges separated by deserts and grasslands. It mixes elements from four major ecosystems - the Rocky Mountains, Sierra Madre Occidental and the Sonoran and Chihuahuan deserts, and Neotropical species reaching their northern ranges, such as jaguars (*Panthera onca*) and ocelots (*Leopardus pardalis*). Sky Island Alliance seeks to build cooperative relationships with landowners in Sonora and public land managers in Arizona to facilitate scientific research, encourage large predator conservation and establish corridors connecting patches of continuous habitat throughout the region. We have conducted wildlife surveys with remote cameras in northern Sonora since 2007 and in Arizona since 2009. Our photographic records cover 23 species of wild mammals, including jaguar, ocelot, puma (*Puma concolor*), black bear (*Ursus americanus*), coati (*Nasua narica*) and four species of skunks (Mephitidae). In 2009 we documented Arizona's first live ocelot, and recently we documented two individual jaguars 30 miles south of the border in Sonora. Our records reveal spatial and temporal activity patterns of wildlife species, their distribution, habitat preference, and corridor use. The project's results have increased our knowledge of borderland wildlife, especially the Sonoran ocelot, and supported the certification of a 10,000-acre private ranch as a wildlife preserve in northern Sonora.

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Evaluación y monitoreo de fauna en la Región de las Islas Serranas con énfasis en felinos neotropicales. La región de las Islas Serranas del noroeste de México y suroeste de Estados Unidos consiste de montañas aisladas separadas por desiertos y pastizales. La región une elementos de cuatro ecosistemas –la Sierra Madre Occidental, las Montañas Rocallosas, los desiertos Sonorense y Chihuahuense y especies Neotropicales que alcanzan aquí su distribución más norteña, como jaguares (*Panthera onca*) y ocelotes (*Leopardus pardalis*). Sky Island Alliance busca construir relaciones de cooperación con propietarios privados en Sonora y encargados de áreas naturales en Arizona para facilitar investigación científica, fomentar la conservación de grandes carnívoros y establecer corredores que conecten hábitats continuos en la región. En este proyecto hemos realizado evaluaciones de fauna con cámaras remotas en el norte de Sonora desde 2007 y en Arizona desde 2009. Nuestros registros fotográficos incluyen 23 especies de mamíferos silvestres, como el jaguar, ocelote, puma (*Puma concolor*), oso negro (*Ursus americanus*), coati (*Nasua narica*) y cuatro especies de zorrillos (Mephitidae). En 2009 documentamos el primer ocelote vivo en el estado de Arizona y recientemente documentamos dos jaguares distintos a 45 kilómetros al sur de la frontera en Sonora. Nuestros registros revelan patrones de actividad de fauna espaciales y temporales, su distribución, preferencia de hábitat y uso de corredores. Los resultados del proyecto han incrementado nuestro conocimiento sobre la fauna en la región fronteriza, especialmente de la subespecie de ocelote Sonorense y respaldan la certificación de una reserva privada de 4,000 hectáreas para fauna en el norte de Sonora.

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Mapping and assessing the environmental impacts of border tactical infrastructure in the Sky Island Region. In this project we mapped the different types of border wall, identified impacts of border infrastructure on public and private lands and conducted spatial analyses within the approximately 200 miles of international border in the Sky Island region. The Sky Island region, bisected by the U.S.-Mexico border, is critically important for its biodiversity and continental connectivity; only on the Arizona side the border is lined with protected areas such as San Bernardino and Buenos Aires National Wildlife Refuges, San Pedro Riparian National Conservation Area, Coronado National Memorial, and several Wilderness Areas. In recent years the construction of border barriers, walls and other tactical infrastructure built to deter human and vehicle traffic across the border has had substantial impacts on ecological processes and created an impermeable boundary with effects that reach far beyond the footprint of the wall. Due to the lack of environmental impact studies, construction of border infrastructure proceeded without input from public land managers or private landowners. With the use of Geographic Information Systems we analyzed and graphically compiled results from over-flights along the border generating photographic data of the current state and effects of infrastructure, field visits to obtain complementary information and ground-truth aerial photographs, and observations of the direct effects of barriers to wildlife movements and the flow of ecological and hydrologic processes.

Trazado de mapas y evaluación de los impactos ambientales de la infraestructura táctica fronteriza en la Región de las Islas Serranas. En este proyecto se trazaron mapas de los diferentes tipos de barreras fronterizas, se identificaron impactos de la infraestructura en áreas del gobierno y privadas, y se realizaron análisis espaciales en cerca de 320 kilómetros de frontera internacional en la Región de las Islas Serranas. La Región de las Islas Serranas, dividida por la frontera internacional México-Estados Unidos, es importante por su biodiversidad y conectividad paisajística a nivel continental; solo en Arizona la frontera esta delineada por áreas naturales protegidas como los Refugios de Fauna Silvestre San Bernardino y Buenos Aires, el Área Nacional de Conservación del Río San Pedro, el Coronado National Memorial, y otras zonas naturales. En años recientes la construcción de barreras, muros y otra infraestructura táctica fronteriza construida para detener el paso de personas y vehículos a través de la frontera ha tenido impactos substanciales en los procesos ecológicos y ha creado una barrera impermeable con efectos que llegan más allá de la huella del muro. Debido a la falta de estudios de impacto ambiental, la construcción de infraestructura fronteriza ha procedido sin la participación de encargados de áreas naturales o propietarios privados. Con el uso de sistemas de información geográfica se analizan y representan gráficamente los resultados de vuelos en la frontera generando información fotográfica del estado actual de la infraestructura, visitas de campo para recabar información complementaria, verificar fotografías aéreas, y observar los efectos directos de las barreras sobre los movimientos de fauna y el flujo de procesos ecológicos e hidrológicos.

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Perennial invasive grass fires threaten to convert the Sonoran Desert ecosystem. Pyrophilic buffelgrass (*Pennisetum ciliare*) is invading many ecosystems in the United States and abroad, including the Sonoran Desert. Buffelgrass, an African bunch grass, poses a significant threat to Saguaro National Park's natural and cultural resources. A buffelgrass-fueled fire is likely to cause unprecedented and irreparable damage to the desert ecosystem. Iconic Sonoran Desert species such as the saguaro cactus and desert tortoise are not fire-adapted and will suffer fire-induced mortality from buffelgrass fueled fires. Buffelgrass will contribute to a positive grass-fire cycle with the potential to convert the Sonoran Desert ecosystem into exotic grassland. Land managers in the Sonoran Desert face novel challenges beyond large scale control treatments, including developing restoration techniques, fire management strategies, and post-fire treatments. The Park has been managing buffelgrass for more than 10 years; we will present fire behavior results, economical and logistical issues of controlling buffelgrass in a wilderness, and lessons learned.

Incendios de zacates perennes invasores amenazan cambiar el ecosistema del Desierto Sonorense. El zacate buffel amante del fuego (*Penisetum ciliare*) está invadiendo muchos ecosistemas en Estados Unidos y el extranjero, incluso el Desierto Sonorense. El buffel, un zacate africano que crece en macollos, representa una amenaza seria para los recursos naturales y culturales del Parque Nacional Saguaro. Un incendio de buffel puede causar un daño sin precedentes e irreparable al ecosistema del desierto. Las especies emblemáticas del Desierto Sonorense, como el sahuaro y la tortuga de los cerros no están adaptados al fuego y sufrirán una mortandad inducida por el fuego de incendios del buffel. El buffel inducirá un ciclo de zacate-fuego con el potencial de convertir el ecosistema del Desierto Sonorense a un pastizal exótico. Los encargados del manejo de recursos naturales del Desierto Sonorense enfrentan nuevos retos además del control en gran escala como son: el desarrollo de técnicas de restauración, estrategias de manejo del fuego, y tratamientos posteriores al incendio. El Parque ha controlado el zacate buffel por más de 10 años; se presentarán resultados de comportamiento del fuego, problemas económicos y logísticos para controlar buffel en un área natural, y las lecciones aprendidas.

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Detecting climate change impacts on birds and their habitats in the southwest United States and northwest México. Failing to incorporate the projected impacts of climate change into habitat management strategies will almost certainly lead to a failure to achieve conservation objectives. Changes in bird populations have long been used to indicate the direction and magnitude of change in ecosystems, and they can help us assess current and future impacts of climate change. This information can then be used by managers to take appropriate conservation action for birds and bird habitat and can help focus investment in overlap between current and future conservation priorities. The goal of this project is to develop a foundation for monitoring environmental change in the Sonoran Joint Venture region. We provide land managers and biologists with methodological tools, data resources, analyses, and training to understand and detect climate change effects, define adaptation options, and increase capacity for making conservation decisions for bird populations and habitats in the areas under their jurisdiction. We use climate and bird observation data to identify locations where we predict the greatest changes in climate, habitats, and bird communities. During a workshop with experts, we will use the locations identified by our analyses to define priority bird species, sites, and regions and develop a coordinated bird monitoring strategy for the region with respect to climate change. We will also develop a bilingual web portal to view predicted changes and store and query data, and provide training opportunities for managers and biologists on the use of these resources, monitoring strategies, and data collection and management.

Cómo detectar los impactos del cambio climático en aves y sus hábitats en el suroeste de Estados Unidos y noroeste de México. Si no se incluyen los impactos previstos del cambio climático en las estrategias de manejo del hábitat muy probablemente no se lograrán los objetivos de conservación. Los cambios en las poblaciones de aves se han usado desde hace tiempo para indicar la dirección y magnitud del cambio en los ecosistemas y pueden ayudar a evaluar los impactos actuales y futuros del cambio climático. Esta información puede ser útil al personal de manejo de recursos para tomar decisiones de conservación para las aves y sus hábitats, y a dar prioridad a la inversión donde coincidan preferencias actuales y futuras de conservación. Este proyecto tiene como meta sentar las bases para el monitoreo del cambio ambiental en la región Sonoran Joint Venture. Se brinda a los encargados de manejo y biólogos metodología, fuentes de datos, análisis y capacitación para entender y detectar los efectos del cambio climático, identificar adaptaciones y aumentar su capacidad para tomar decisiones de conservación para las poblaciones de aves y sus hábitats en las áreas bajo su jurisdicción. Utilizamos datos climáticos y observaciones de aves para identificar las localidades donde pronosticamos los cambios mayores en clima, hábitat y comunidades de pájaros. En un taller con especialistas, usaremos las localidades identificadas en nuestros análisis para determinar las especies de aves, sitios y regiones prioritarias y planear una estrategia coordinada para el monitoreo de aves en la región con relación al cambio climático. También diseñaremos un portal de internet bilingüe para ver los cambios previstos, subir y guardar información y consultas. Así mismo tendremos oportunidades de capacitación para el personal de áreas de conservación y biólogos sobre el uso de estos recursos, estrategias de monitoreo, toma de datos y manejo.

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Spatial and temporal analysis of predator-prey interactions within Saguaro National Park. From April 2011 to April 2012, we investigated the spatial and temporal patterns of mammals within Saguaro National Park's Rincon and Tucson Mountain Districts. Data was analyzed using Cuddeback Capture camera images provided by Saguaro National Park. The 91,440 acre park was divided into 1-km² plots ranging in elevation from 664 m to 2,641 m using a grid feature of ArcMap. The location of the plots as well as the camera placement in each plot was randomly chosen using a number generator in ArcMap. Over a twelve-month period, images from 126 cameras were analyzed. The location and time of mammal images were recorded and evaluated and correlations of predator-prey interactions were examined based on these factors. Our findings suggest that the mammal community is successfully coexisting both temporally and spatially within Saguaro National Park. Knowledge of how mammals utilize the landscape of Saguaro National Park will enable wildlife managers to implement more effective conservation and management strategies.

Análisis espacial y temporal de las interacciones entre depredador y presa del Parque Nacional Saguaro. Se hizo un estudio de los patrones espaciales y temporales de mamíferos en los distritos *Tucson Mountain* y *Rincon* del Parque Nacional Saguaro, desde abril de 2011 a abril de 2012. La información se analizó usando imágenes de cámaras ‘Cuddeback Capture’ del Parque. El área del parque (370 has) se dividió en parcelas de 1-km² variando en elevación de 664 m a 2,641 m usando una cuadrícula de ArcMap. La ubicación de las parcelas, así como la colocación de la cámara en las mismas, fue seleccionada al azar usando un generador de números de ‘ArcMap’. Se analizaron las imágenes de 126 cámaras generadas en un período de 12 meses. La ubicación y tiempo de las imágenes de mamíferos se capturaron y analizaron, y basado en estos factores se examinó las interacciones entre el depredador y la presa. Nuestros resultados sugieren que la comunidad de mamíferos tiene una coexistencia exitosa tanto espacialmente como temporalmente en el Parque Nacional Saguaro. El saber cómo los mamíferos utilizan el área del Parque permitirá que los encargados de manejo de fauna implementen estrategias de conservación y manejo más efectivas.

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Monitoring of medium and large mammals in the Sierra La Madera, Sonora, Mexico. Sierra La Madera is part of the group of mountains called “Sky Islands” Madrean Archipelago and comprises the Reserve Fraction V “Ajos-Bavispe”. The objective was to determine the composition of medium and large mammals of wildlife in the area, through the use of camera traps. Were placed 18 camera traps WildView 2® brand in three monitoring campaigns: August-September, September to November and November-December. The first and second campaign was placed cameras on the farms La Bellota, La Palmita y San Fernando, the third campaign was placed on ranches La Mesa, El Mezquite y Brecha CONAFOR, located in the municipalities of Cumpas, Moctezuma, and Huásabas y Villa Hidalgo, where there is thorny scrubs, oak and pine forest. The results show 17 species in five orders Carnivora, Artiodactyla, Didelphimorphia, Lagomorpha and Rodentia. Additionally, there was four species of birds and animals.

Monitoreo de mamíferos medianos y grandes en Sierra La Madera, Sonora, México. Sierra La Madera forma parte del conjunto de sierras denominadas “Islas Serranas” del Archipiélago Madreño y comprende la Fracción V de Reserva “Ajos-Bavispe”. El objetivo fue determinar la composición de fauna silvestre de mamíferos medianos y grandes en el área, a través del uso de cámaras-trampa. Se colocaron 18 cámaras-trampa marca WildView 2® en tres campañas de monitoreo: agosto-septiembre, septiembre-noviembre y noviembre-diciembre. La primera y segunda campaña se colocó cámaras en los ranchos La Bellota, La Palmita y San Fernando; la tercera campaña se colocó en los ranchos La Mesa, El Mezquite y Brecha CONAFOR, estos ubicados en los municipios de Cumpas, Moctezuma, Huásabas y Villa Hidalgo, donde existe matorral espinoso, bosque de encino y pino. Los resultados muestran 17 especies en cinco órdenes Carnívora, Artiodactyla, Didelphimorphia, Lagomorpha y Rodentia. Adicionalmente se registró cuatro especies de aves, así como animales domésticos.

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Conceptual model of plant responses to climate and implications for monitoring for ecosystem change. Although land management agencies have expressed increasing concern for monitoring for ecosystem health and resiliency in a changing climate, current practices, designed primarily to monitor for erosion and impacts of livestock and focusing on a small number of the most resilient (and economically desired) species, are inadequate to assess early change in vegetative communities or ecosystems. Optimal and adverse climatic conditions result in different vegetative assemblages. Ecosystem change will be more readily seen if the focus is on those species that respond positively to optimal conditions but are absent or non-reproductive in adverse conditions: what isn’t present may be more important than what is. The conceptual model is a starting point for determining how land managers can identify ecosystem change before it reaches the tipping point of system collapse.

Modelo conceptual de las respuestas de plantas al clima y sus implicaciones en el monitoreo de cambios en el ecosistema. Aunque las agencias de manejo de recursos naturales han expresado una mayor preocupación por el monitoreo del equilibrio ecológico y la resistencia del ecosistema en un clima cambiante, las prácticas actuales diseñadas principalmente para el monitoreo de la erosión y los impactos del ganado y centrándose en unas cuantas de las especies más resistentes (y económicamente deseables) son inadecuadas para evaluar los primeros cambios en las comunidades vegetales o ecosistemas. Las condiciones climáticas adversas y óptimas producen diferentes agrupaciones de plantas. El cambio en el ecosistema se podrá ver más fácilmente si el trabajo se enfoca en las especies que responden de forma positiva a las condiciones óptimas, pero están ausentes o sin reproducir en condiciones adversas: las ausentes pueden ser más importantes que las presentes. El modelo conceptual es el punto de partida para ayudar a los encargados de manejo a identificar el cambio en el ecosistema antes de alcanzar el momento crítico del desplome del sistema.

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Sustaining the grassland sea: Regional perspectives on restoring and protecting the Sky Island region’s most intact grassland valley landscapes. Grasslands of the Sky Islands Region once covered over 11 million acres in southeastern Arizona and adjacent portions of New Mexico, Sonora, and Chihuahua. Attempts to evaluate current ecological conditions suggest that approximately two third of this remains as intact or restorable grassland habitat. These grasslands provide watershed services such as flood control and aquifer recharge across the region, and continue to support dozens of species of concern. Prioritizing conservation interventions for these remaining grassland blocks has been challenging. Reliable data on condition and conservation value of grasslands in the region have not been systematically summarized. State and

national boundaries further complicate efforts to identify where the best remaining habitats and populations of grassland obligate wildlife still exist. We present results of an effort to merge grassland condition assessments from adjacent geographies, compile information on target species locations, and identify “priority grassland valley landscapes” across the region. We evaluate these priority landscapes in terms of the number of target species, critical threats, and enabling conditions for long-term conservation success such as activity by local cooperative groups dedicated to sustaining their landscapes. Lastly, we discuss the opportunities and challenges of designing and implementing effective restoration activities in these large multi-jurisdictional landscapes.

Conservación del mar de pastizales: Perspectivas regionales sobre la restauración y protección del paisaje de pastizal más intacto de la región de las Islas Serranas. Los pastizales de la región de las Islas Serranas, años atrás, cubrieron más de 4.5 millones de hectáreas en el sureste de Arizona y partes adyacentes de Nuevo México, Sonora y Chihuahua. Las evaluaciones de las condiciones ecológicas actuales indican que aproximadamente dos terceras partes están intactas o son hábitat de pastizales recuperables. Estos pastizales proporcionan servicios de cuencas, tales como control de inundaciones y recarga de los acuíferos en la región, y mantienen a decenas de especies de interés. Priorizar las intervenciones para la conservación de estos bloques restantes de pastizales ha sido un desafío. Datos confiables sobre la condición y valor para la conservación de los pastizales de la región no han sido sistemáticamente condensados. Fronteras estatales y nacionales, complican aún más los esfuerzos para identificar dónde quedan los mejores hábitats y las poblaciones de vida silvestre dependiente de los pastizales que aún existen. Presentamos los resultados de un estudio para incorporar las evaluaciones de la condición de los pastizales geográficamente adyacentes, recopilar información sobre la ubicación de especies de interés, e identificar “paisajes de llanuras de pastizal prioritarios” de la región. Evaluamos estos paisajes prioritarios en términos del número de especies importantes, amenazas críticas y condiciones propicias para el éxito de la conservación a largo plazo como la participación de grupos locales colaborativos dedicados a mantener sus áreas naturales. Por último, analizamos las oportunidades y retos de diseño e implementación de medidas de restauración efectivas en estas grandes áreas naturales de varias jurisdicciones.

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Science on the Sonoita Plain. The Sonoita Valley Planning Partnership (SVPP) is a voluntary ad hoc association of agencies, user groups, conservation organizations, and individuals who come together to achieve community-oriented solutions to local and national issues affecting public lands within the Sonoita Valley. The SVPP was created in 1995 in response to BLM's initiation of a collaborative planning process for Las Cienegas National Conservation Area. The SVPP meets quarterly and provides a forum for participants to share information and work together to perpetuate naturally functioning ecosystems while preserving the rural, grassland character of the Sonoita Valley for future generations. Science on the Sonoita Plain symposiums are held annually to bring together and share results of scientific investigations occurring within and informing us about the unique and diverse resources of the Sonoita Plain in the upper watersheds of Cienega Creek, Sonoita Creek, and the Babocomari River. The third annual symposium was held on June 4, 2011; the next is scheduled for June 9, 2012. While several groups in the region organize lectures, just a few host annual events designed to concentrate scientists, community members, and agency staff to learn together about their local area. We welcome attendees and recommend this approach for other local areas.

Ciencia en la llanura de Sonoita. The Sonoita Valley Planning Partnership (SVPP) es una asociación voluntaria de agencias, grupos de usuarios, organizaciones de conservación e individuos que se formó para buscar soluciones dirigidas a la comunidad sobre temas locales y nacionales que afectan las áreas naturales del valle de Sonoita. La SVPP fue creada en 1995 como respuesta al proceso colaborativo del BLM para planear el Área Nacional de Conservación de Las Ciénegas. La SVPP se reúne trimestralmente y es un foro donde los participantes comparten información y trabajan juntos para conservar los ecosistemas naturales y preservar el carácter de pradera rural del valle de Sonoita para las generaciones futuras. Los simposios de ciencia de la llanura de Sonoita se realizan cada año para compartir resultados de investigaciones científicas e información sobre la diversidad de los recursos naturales de la llanura de Sonoita en la cuenca alta de Cienega Creek, Sonoita Creek, and the Babocomari River. El tercer simposio anual se llevó a cabo el 4 de junio 2011; el próximo está programado para el 9 de junio 2012. Aunque varios grupos de la región organizan conferencias, sólo unos ofrecen eventos anuales diseñados para unir a científicos, miembros de la comunidad y personal de las agencias para juntos informarse sobre su zona local. Invitamos a que nos acompañen y recomendamos este enfoque para otras regiones locales.

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Top predator extinctions in drying streams modify community structure and ecosystem functioning. Climate change and water withdrawals in the Madrean Sky Island region are causing many once-perennial streams to fragment or dry completely. One of the most notable changes associated with this transition is the disappearance of large aquatic predators, such as fish and the invertebrate top predator *Abedus herberti* (Hemiptera: Belostomatidae). These extinctions presumably cause changes in stream community structure and functioning, however manipulative experiments are necessary to disentangle the effects of local predator extinctions from other co-occurring environmental changes. We seeded 16 mesocosms with stream invertebrates, removed *Abedus* from 8 mesocosms as a treatment, and assessed community and ecosystem changes after 6 weeks. We found that the removal of *Abedus* initiated a trophic cascade resulting in decreased algal biomass, likely caused by the release of the algae-grazing mayfly *Callibaetis* from *Abedus* predation pressure. *Abedus* removal also affected overall invertebrate community structure. The abundance and diversity of secondary predators were higher in mesocosms without *Abedus*, suggesting a competitive release

of these smaller predators. Our findings demonstrate that the indirect biotic effects of stream drying can be as important as abiotic effects and must be considered when planning aquatic conservation in the region.

La extinción de los depredadores principales en riachuelos que se están secando modifica la estructura de la comunidad y funcionamiento del ecosistema. El cambio climático y la extracción de agua en la Región de las Islas Serranas Madreñas están causando que muchos arroyos perennes se fragmenten o se sequen por completo. Uno de los cambios más notables asociados con esta transición es la desaparición de grandes depredadores acuáticos, como peces y el depredador principal de los invertebrados *Abedus herberti* (Hemiptera: Belostomatidae). Estas extinciones probablemente causan cambios en el funcionamiento y la estructura de la comunidad del riachuelo, sin embargo, hacen falta experimentos de manipulación para separar los efectos de la extinción de los depredadores locales de otros cambios ambientales concurrentes. Una muestra de invertebrados de arroyos se introdujo en 16 mesocosmos, en ocho de los cuales se extrajo *Abedus* como tratamiento, y se evaluaron cambios en la comunidad y el ecosistema después de 6 semanas. La eliminación de *Abedus* inició una cascada trófica que resultó en la disminución de la biomasa de algas, probablemente causado por la falta del depredador *Abedus* sobre la mosca del agua *Callibaetis* que se alimenta de algas. La eliminación de *Abedus* también afectó la estructura general de la comunidad de invertebrados. La abundancia y diversidad de depredadores secundarios fueron mayores en los mesocosmos sin *Abedus*, lo que sugiere menos competencia entre estos depredadores más pequeños. Nuestros hallazgos demuestran que los efectos bióticos indirectos de riachuelos que se están secando pueden ser tan importantes como los efectos abióticos y deben ser considerados en la planificación de la conservación acuática en la región.

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Habitat type and permanence determine local aquatic invertebrate community structure in the Madrean Sky Islands. Aquatic habitats in the Madrean Sky Islands (MSI) consist of a matrix of perennial and intermittent stream segments, seasonal rain ponds, and artificial cattle tank habitats that all contribute to the regional biodiversity of aquatic macroinvertebrates. Although environmental conditions and aquatic communities are generally quite distinct in lotic and lentic habitats, MSI streams are characterized by isolated perennial pools for much of the year, and thus seasonally approximate lentic environments. In this study, we compared habitat characteristics and Coleoptera and Hemiptera assemblages of stream pools with those of true lentic habitats (seasonal ponds and cattle tanks) across the MSI. We identified 150 species across the 38 study sites, with distinct faunas found in stream pools versus seasonal ponds. Stream-exclusive species included many long-lived and poor dispersing species, while pond-exclusive species tended to have rapid development times and good dispersal abilities. At a smaller set of streams, we also compared aquatic invertebrate community structure between perennial and intermittent streams. We found lower diversity in intermittent streams, but most intermittent stream species were specialists not found at perennial sites. We suggest that, in addition to perennial streams, seasonal aquatic habitats should also be a focus of conservation planning in the MSI.

El tipo de hábitat y la permanencia determinan la estructura de la comunidad local de invertebrados acuáticos en las Islas Serranas Madreñas. El hábitat acuático de las Islas Serranas Madreñas (ISM) está compuesto de una red de riachuelos intermitentes y perennes, charcos temporales y repesos artificiales de abrevadero, donde todos contribuyen a la biodiversidad regional de especies acuáticas. Aunque las comunidades acuáticas y las condiciones ambientales prevalecientes en riachuelos y charcos son por lo general muy diferentes, los riachuelos de las ISM se caracterizan por tener tinajas perennes aisladas la mayor parte del año y son hábitats casi lénticos. En este estudio se compararon las comunidades acuáticas de coleópteros y hemípteros de tinajas de arroyos con hábitat léntico verdadero (charcos temporales y abrevaderos) a lo largo de las ISM. Se identificaron 150 especies a lo largo de 38 sitios de estudio. Entre los repesos de abrevaderos y las tinajas se presentó fauna diferente. Las especies exclusivas de las tinajas incluyeron muchas especies longevas y de pobre dispersión, mientras que las especies exclusivas de los repesos tuvieron en general un periodo de rápido desarrollo y una buena dispersión. En otras seis corrientes, se compararon las comunidades de invertebrados acuáticos entre corrientes perennes e intermitentes. Se encontró menos diversidad de invertebrados en corrientes intermitentes, pero la mayoría de estas especies fueron especialistas y no se encontraron en corrientes perennes. Se sugiere, que en adición a los arroyos perennes, también se les preste atención a los charcos temporales para la conservación de organismos acuáticos en las ISM.

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Mammal richness of San Bernardino Ranch, Agua Prieta, Sonora, Mexico. Historically, economic activities such as grazing and intensive agriculture have been the support of San Bernardino Ranch, however this has caused environmental damage in the region. The ranch has mayor ecological value because of its semi desert grasslands, riparian areas and a ciénega, in which restoring efforts take place; we harvest water with retaining walls. Mammals are important in the ecosystem because they occupy several niches, therefore by knowing the species present in each ecosystems, we will also know the status and healthiness of the ecosystem. We used direct and indirect methods; we identified 20 species of terrestrial mammals. We can compare richness and diversity of the ranch to the San Bernardino National Wildlife Refuge, in the other side of the border; in which restoration efforts started earlier.

Riqueza de mamíferos del rancho San Bernardino, municipio de Agua Prieta, Sonora, México. Históricamente, en el rancho San Bernardino se realizaron actividades económicas como son la ganadería y agricultura intensivas, las cuales provocaron el deterioro de los ecosistemas de la región. El rancho es de gran importancia ecológica debido a que cuenta con varios tipos de hábitats de interés para su conservación como el pastizal semidesértico, el ribereño y una gran ciénega, la que se está restaurando con la recolección de agua de lluvia por medio de gaviones. Los mamíferos son importantes en el ecosistema ya que ocupan una gran variedad de nichos, y el conocer las especies actuales que habitan los diferentes sitios del rancho, nos indicará el balance ecológico del hábitat. Para conocer los mamíferos presentes se usaron métodos de muestreo directo e indirecto con los cuales se identificaron 20 especies de mamíferos terrestres. Con éstos datos se puede empezar a comparar la riqueza y diversidad de especies en este rancho y las especies presentes en el San Bernardino National Wildlife Refuge, ubicado exactamente del otro lado de la frontera, el cual tiene más tiempo con obras de restauración.

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Flora of the Rancho Los Fresnos grasslands: A high-desert crossroads between the Sonoran, Chihuahuan and Great Plains floras. Rancho Los Fresnos, a private nature preserve at approximately 1500 m along the U.S. border in northern Sonora, protects over 4,000 hectares of desert grasslands, oak woodland and riparian vegetation along the headwaters of the San Pedro River. The Los Fresnos flora consists of 245 species in 65 families, with over a third of these species in the three families Poaceae, Asteraceae, and Fabaceae. Approximately 70% of the species are perennial. Blooming is distributed roughly bimodally between spring and fall, with a slight preponderance of fall-blooming species. Due the presence of springs, permanent streams, and a large marsh or *ciénega*, Los Fresnos has a relatively rich riparian flora. Two species, *Lilaeopsis schaffneriana* subsp. *recurva* and *Echeandia flavescens*, are listed as threatened or endangered in the US. Seven species, among them *Sporobolus giganteus*, are apparently new records for the state of Sonora. Multivariate comparison of Los Fresnos with 246 North American floras showed almost equal floristic affinity with adjacent Sonoran deserts and Chihuahuan desert floras of NM, TX and north-central Mexico, as well as to short grass prairies of the SW Great Plains and semi-arid sites in central Mexico.

Flora de los pastizales del rancho Los Fresnos: un cruce de floras de desiertos altos entre el Desierto Sonorense, Desierto Chihuahuense y las Grandes Llanuras. El rancho Los Fresnos, una reserva natural privada con alrededor de 1500 m de la frontera de México con E.U. en el norte de Sonora, protege más de 4,000 hectáreas de pastizal del desierto, encinal y vegetación ribereña a lo largo del nacimiento del río San Pedro. La flora de Los Fresnos consta de 245 especies en 65 familias, con más de la tercera parte de estas especies en tres familias: Poaceae, Asteraceae y Fabaceae. Casi el 70% de las especies son perennes. En general la floración presenta un patrón bimodal entre primavera y otoño, con un ligero predominio de las especies con floración de otoño. Debido a la presencia de agujajes, riachuelos permanentes y una gran ciénega, Los Fresnos cuenta con una flora ribereña relativamente diversa. Dos especies *Lilaeopsis schaffneriana* subsp. *recurva* y *Echeandia flavescens* están clasificadas como amenazadas o en peligro de extinción en E.U. Siete especies, entre ellas *Sporobolus giganteus*, parecen ser registros nuevos para el estado de Sonora. En una comparación multivariada de Los Fresnos con 246 floras de América del Norte se encontró una afinidad florística casi igual con las floras adyacentes del Desierto Sonorense y el Desierto Chihuahuense en Nuevo México, Texas y la región norte centro de México, así como las praderas de zacates cortos del suroeste de Las Grandes Llanuras y regiones semiáridas del centro de México.

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Planning river restoration in a changing climate. On December 7-11, 2010, a conference was convened in Tucson, Arizona that brought together river practitioners, scientists, private citizens, and conservationists from federal and state agencies, academic institutions, and non-governmental organizations (NGOs) in the southwestern United States (U.S.), northern Mexico, and southeastern Australia to discuss lessons learned from their river restoration experiences. Key conference topics included the development of viable restoration objectives, planning and implementing restoration, monitoring results, climate change, environmental flow, native fish conservation, and restoration along trans-boundary rivers. Results are being incorporated into an applied river restoration guidebook, which summarizes the main steps of developing a stream restoration project, from planning and implementation to monitoring and evaluation. Some of the main lessons from the conference and overall strategy of the guidebook will be presented, with emphasis on the guidebook chapter that reviews considerations for developing river restoration in a changing climate.

Restauración de ríos bajo los efectos del cambio climático. Del 7 al 11 de diciembre del 2010 se llevó a cabo una reunión en Tucson, Arizona, en la cual se congregaron expertos en ríos, científicos, ciudadanos y personal dedicado a la conservación de agencias estatales, federales, instituciones académicas y organizaciones no gubernamentales (ONG) del sureste de Estados Unidos, norte de México y sureste de Australia, con la finalidad de compartir experiencias con relación a la restauración de ríos. Los tópicos claves de las conferencias incluyeron desarrollo de metas de restauración viables, planeación e implementación de la restauración, monitoreo de resultados, cambio climático, flujo ambiental, conservación de peces nativos y la restauración de ríos transfronterizos. Los resultados se están compilando en una guía de restauración de ríos, donde se resume como desarrollar proyectos de restauración, desde la planeación y la implementación, hasta el monitoreo y evaluación. Se presentarán enseñanzas de la reunión y el contenido general del libro, con especial énfasis en el capítulo de restauración de ríos bajo efectos del cambio climático.

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Long distance commute by Lesser Long-nosed Bats (*Leptonycteris yerbabuena*) to visit residential hummingbird feeders. Each spring, thousands of lesser long-nosed bats (*Leptonycteris yerbabuena*) migrate from México to northern Sonora and southern Arizona to have their young and to forage on nectar, pollen and fruit of columnar cacti. Once the pups are volant, the population begins to disperse across the grasslands of southeastern Arizona, foraging on flowering agaves (*Agave palmeri*) and day-roosting in Madrean Sky Islands during their seasonal migration back to México. Although the grasslands surrounding Arivaca, Arizona have no naturally occurring fields of agaves, nectar bats are documented visiting area hummingbird feeders to obtain sugar water. To better understand foraging patterns by these bats in an area with no natural food plants, we radio-tracked 28 lesser long-nosed bats in 2010 - 2011. We captured bats at area hummingbird feeders and tracked them to a day-roost in the Santa Rita Mountains, approximately 25 miles away. We discovered that bats nightly performed a long-distance commute from the Santa Rita Mountains to Arivaca, bypassing available hummingbird feeders closer to their day-roost. It may be that the large colony size in the day-roost necessitates long-distance dispersal as a mechanism to reduce competition for limited food resources.

Desplazamientos largos de murciélagos nectarívoros (*Leptonycteris yerbabuena*) para visitar bebederos residenciales de chuparrosas. Cada primavera miles de murciélagos nectarívoros (*Leptonycteris yerbabuena*) migran desde México hasta el norte de Sonora y el sur de Arizona para parir y alimentarse de néctar, polen y frutos de cactus columnares. Una vez que las crías pueden volar, la población empieza a dispersarse en los pastizales del sureste de Arizona, alimentándose de las flores de maguey (*Agave palmeri*), encontrando refugio diurno en las Islas Serranas Madreñas durante su migración anual de regreso a México. Los pastizales que rodean Arivaca, Arizona no cuentan con poblaciones de magueyes, aún así los murciélagos nectarívoros se han documentado visitando los bebederos de chuparrosas para tomar el agua azucarada. Con el fin de tener un mejor conocimiento de los patrones de alimentación de estos murciélagos en un área sin plantas alimenticias nativas, de 2010 a 2011, usamos la técnica de rastreo con radio telemetría en 28 murciélagos nectarívoros. Capturamos los murciélagos en los bebederos de chuparrosas y los rastreamos a sus refugios diurnos en la Sierra Santa Rita, ca. 40 km de distancia. Descubrimos que cada noche los murciélagos se desplazaron una larga distancia desde la Sierra Santa Rita a Arivaca, eludiendo los bebederos más cercanos a sus refugios diurnos. Una explicación podría ser que las colonias grandes de los refugios diurnos necesitan una dispersión larga como mecanismo para reducir la competencia por recursos alimenticios limitados.

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Biodiversity effects on ecosystem function due to land use: The case of buffelgrass savannas in the Sky Islands seas in the Central Region of Sonora. Buffelgrass savannas have been an important landscape in cattle grazing ranches in Sonora over the past 50 years or so. Changes in land use results in biodiversity changes that may result in ecosystem functional changes, however these are less documented. Although fire cycle driven processes have been proposed for Buffelgrass savannas, this is not generally the case, and other processes seem to be driving ecosystem function. Several years of studying above- and below ground processes allow us to propose how water and nutrient dynamics change in established buffelgrass savannas, as well as how biodiversity changes affect functional processes in arid and semiarid ecosystems. Water and nutrient biogeochemical cycles changed in buffelgrass dominated savannas with regard to those in natural ecosystems, following effects of land use changes in soil biological and physical changes. Our findings may be extrapolated to what could be expected to happen to other highly invaded areas where buffelgrass is becoming a dominant exotic species.

Cambios en el uso del suelo afectan la biodiversidad y la función del ecosistema: El caso de pastizales de zacate buffel en las Islas Serranas del centro de Sonora. Los pastizales de buffel han sido comunes en los ranchos ganaderos de Sonora en los últimos 50 años. Los cambios del uso del suelo producen cambios en la biodiversidad y pueden resultar en cambios funcionales del ecosistema, los cuales han sido poco documentados. Aunque los procesos causados por incendios han sido propuestos para pastizales de buffel, esto no es generalmente el caso, y otros procesos parecen afectar la función del ecosistema. Varios años de estudio de los procesos sobre y debajo del suelo, nos permitieron registrar como la dinámica del agua y los nutrientes cambian en praderas de buffel y como los cambios en la biodiversidad afectan los procesos funcionales de ecosistemas áridos y semiáridos. Debido al efecto del cambio del uso del suelo en los procesos físicos y biológicos, los ciclos biogeoquímicos de agua y nutrientes cambian en pastizales dominadas por buffel comparados con ecosistemas naturales. Nuestros resultados pueden extrapolarse a otras áreas altamente invadidas donde el buffel es la especie exótica dominante.

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Effects of roads on wildlife: A review of impacts, mitigation and implications within the Sky Islands. Roads are conspicuous and pervasive features of landscapes and represent one of the most significant anthropogenic impacts on natural areas and wildlife. The goal of this review is to summarize recent studies on road impacts on wildlife and identify gaps in our understanding of the topic in the Madrean Archipelago. The sky islands region is defined by natural levels of fragmentation due to geography; however, human population growth and transportation needs threaten to exacerbate levels of isolation in the region. We review road ecology related peer-reviewed publications and governmental research reports and synthesize geography, biodiversity, and studies' focus. Study areas are concentrated along highways and state routes in Arizona. A taxonomic bias toward large mammals is evident. Despite a prevalence of studies on wildlife road crossing, most research focuses

on distribution and movements; whereas population impacts are rarely described. Our review will help to guide the future direction of research and management in the Madrean Archipelago to minimize road impacts.

Efecto de carreteras en fauna silvestre: análisis de impactos, mitigación y consecuencias en las Islas Serranas. Las carreteras, una característica visible y generalizada del paisaje, representan uno de los impactos antropogénicos más significativos de las áreas naturales y fauna silvestre. El objetivo de este análisis es condensar los estudios recientes sobre impactos de carreteras en fauna silvestre e identificar lagunas de información sobre el Archipiélago Madreño. Las islas serranas se definen naturalmente por diferentes niveles de fragmentación debido a la geografía de la región, sin embargo el crecimiento de la población humana y por ende la necesidad de transportación amenaza con aumentar los niveles de aislamiento de la región. El análisis incluye publicaciones científicas y reportes gubernamentales sobre ecología de carreteras, y se sintetiza la geografía, biodiversidad y estudios relevantes. Los sitios de estudio se distribuyen a lo largo de autopistas federales y carreteras estatales en Arizona. El sesgo taxonómico hacia mamíferos mayores es evidente. A pesar de la frecuencia de estudios de fauna silvestre cruzando carreteras, la mayoría se enfoca en distribución y movimiento; y por lo general se ignora el impacto sobre la población. Este análisis servirá para guiar la investigación y manejo futuros para minimizar impactos de carreteras en el Archipiélago Madreño.

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Conserve to Enhance: An innovative mechanism for environmental benefits. Arizona's riparian ecosystems have been susceptible to degradation because state water laws do not consider environmental water needs. This lack of legal authority has led to surface water diversion and groundwater consumption with little or no consideration of impacts on water dependent ecosystems (Megdal et al. 2011). To help address this challenge, The University of Arizona Water Resources Research Center (WRRC) has developed and is implementing the innovative Conserve to Enhance (C2E) mechanism to bring the environment to the table as a paying water customer. Conserve to Enhance addresses the perception that municipal water conservation does not directly benefit the environment (Schwarz and Megdal 2008). C2E offers water customers the option to donate money saved through voluntary water conservation actions to projects that support environmental water needs. The Sonoran Institute, Tucson Water, Watershed Management Group, and WRRC have partnered to implement C2E in Tucson since January 2011. This poster details outcomes from the first year of the Tucson pilot, including the program development process, the amount of funds raised, and the quantity of water saved. Lessons learned during program development in Tucson will help inform implementation of C2E in other communities.

Conservar para Mejorar: un mecanismo innovador con beneficios ambientales. Los ecosistemas ribereños de Arizona han sido susceptibles a la degradación debido a las leyes estatales que no toman en cuenta las necesidades de agua del medio ambiente. Esta falta de autoridad legal ha dado lugar a la desviación del agua en la superficie y el consumo de aguas subterráneas con poca o ninguna consideración a los impactos en los ecosistemas que dependen del agua (Megdal et al. 2011). Para enfrentar este desafío, la Universidad de Arizona Centro de Investigación sobre los recursos del agua "Water Resources Research Center" (WRRC) ha desarrollado y está implementando el mecanismo innovador de Conservar para Mejorar "Conserve to Enhance" (C2E) para poner al medio ambiente en la mesa de discusiones como un cliente más que paga el agua. Conservar para Mejorar aborda la percepción de que la conservación del agua municipal no beneficia directamente al medio ambiente (Schwarz y Megdal 2008). C2E ofrece a los consumidores la opción de donar el dinero ahorrado en la conservación voluntaria de agua a proyectos que apoyan las necesidades de agua del medio ambiente. El Instituto Sonorense, Organismo de Agua de Tucson, Grupo de Manejo de Cuencas Hidrográficas y WRRC se unieron para poner en práctica C2E en Tucson desde enero de 2011. Este cartel detalla los resultados del primer año de este proyecto piloto, el proceso de desarrollo del programa, la cantidad de fondos recaudados, y la cantidad de agua ahorrada. Las lecciones aprendidas durante el desarrollo del programa en Tucson servirán para aplicar el C2E en otras comunidades.

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Utilization of Satellite Imagery to Evaluate and Predict Out-Year Post-Fire Watershed Response and Potential Application in the Southwest. Burned Area Emergency Response (BAER) teams, along with other agencies that have jurisdictional responsibility (Natural Resource Conservation Service, state, counties, cities, etc.), prescribe and implement treatments based on expected post-fire response and associated threats to life, property, and resources. Vegetative cover is often used to evaluate watershed recovery and the start of a return to pre-fire response behavior. The objective of this project is to use remote sensing technologies to assess the rate of natural vegetative regeneration post-fire and evaluate the level of risk for continued increased post-fire watershed response. If remote sensing indices are effective in determining the rate of natural vegetative recovery in burned areas, then we can determine how peak flows, debris flows, and sedimentation and erosion factors have changed, and this information will enable us to determine the level of risk for an area? This discussion summarizes steps taken, initial findings from the Horseshoe 2, Monument, and other fires, and identifies future needs to implement a decision support tool with national application that will give land managers and emergency response personnel an indication of the level of risk relative to pre-fire or immediate post-fire levels.

El uso de imagen satelital para evaluar y predecir la recuperación posterior a incendios en las cuencas y su aplicación potencial en el Suroeste Norteamericano. Las brigadas de BAER (Respuesta de Emergencia para Áreas Incendiadas, por sus siglas en inglés), junto con otras agencias que tienen responsabilidad jurídica (Servicio de Conservación de Recursos Naturales, estado, municipios, ciudades, etc.), prescriben e implementan tratamientos basados en respuestas esperadas posteriores al incendio y amenazas a la vida, propiedad y recursos. La cobertura vegetal se emplea para evaluar la recuperación de la cuenca y el regreso al estado previo al incendio. El objetivo de este proyecto es emplear tecnologías como sensores remotos para analizar el tiempo de regeneración de cobertura vegetal y evaluar el nivel de riesgo de recuperación de la cuenca, después del incendio. Si los índices desarrollados a partir de sensores remotos son efectivos en la determinación de recuperación de cobertura vegetal en zonas quemadas, entonces se pudiera determinar la corriente máxima, flujo de detritos, sedimentación, erosión, y usar esta información para determinar niveles de riesgo. Este trabajo analiza resultados preliminares de los incendios “Horseshoe 2”, “Monument”, y otros, e identifica necesidades futuras para implementar una estrategia de decisión, con aplicaciones a nivel nacional que permita a los encargados de manejo de recursos y brigadistas identificar el nivel de riesgo previo y posterior al incendio.

COGAN, ROGER C. National Audubon Society, Appleton-Whittell Research Ranch, Elgin, AZ.

Rattlesnake Wintering Sites at the Appleton-Whittell Research Ranch. The Research Ranch is an 8000-acre sanctuary and research facility in the semi-arid grasslands of southeastern Arizona managed by the National Audubon Society. At the Research Ranch we work to protect native species and the natural systems that occur both on the preserve and the surrounding area. Snakes are an integral element within all of the habitats where they are found. Snakes not only help maintain the fitness of their prey but they themselves are food for a wide variety of predators. They are a vital part of the landscape at all times of the year, yet little is known about the habitat requirements necessary for successful overwintering. Four rattlesnake species are known to occur at the Research Ranch: Western Diamondback (*Crotalus atrox*), Black-tailed (*Crotalus molossus*), Rock (*Crotalus lepidus*) and Mohave (*Crotalus scutulatus*) rattlesnakes. During the months of February, March and April 2011, a survey for potential rattlesnake wintering sites was conducted. This search was conducted whenever time permitted or when weather conditions seemed most likely to expose snakes at the surface. Surveys during February, March and April are conducted when climate conditions are optimal for snakes to exit their den sites for brief periods. Confirmed den sites are photographed and georeferenced and, if possible, the snakes are photographed for vouchering.

Guaridas de invierno de víboras de cascabel en la estación biológica Appleton-Whittell Research Ranch. El centro de investigación es un santuario de 3,237 has en los pastizales semiáridos del sureste de Arizona a cargo de la Asociación Nacional Audubon. En la estación se trabaja para proteger las especies nativas y los sistemas naturales que ocurren tanto en la reserva como en el área adyacente. Las serpientes son un elemento esencial de todos los hábitats donde se encuentran y no sólo mantienen el balance de sus presas sino que también son el alimento de una gran variedad de depredadores. Aunque son parte vital del ecosistema todo el año, se conoce muy poco sobre los requisitos del hábitat para que sobrevivan el invierno. En esta reserva ocurren cuatro especies de víboras de cascabel: *Crotalus atrox* (cascabel de diamantes), *Crotalus molossus* (cascabel de cola negra), *Crotalus lepidus* (chichámora) y *Crotalus scutulatus* (cascabel mohavense). En febrero, marzo y abril de 2011 se realizó un censo de los sitios potenciales de invierno para víboras de cascabel. Las condiciones climáticas de esos tres meses son óptimas para que las serpientes salgan de sus guaridas por tiempos cortos, lo que se aprovecha para censar. Las guaridas donde se confirma su presencia se fotografían, se ubican con coordenadas y cuando es posible también se toman fotos de las serpientes para documentarse en una colección.

COGAN, ROGER C. National Audubon Society, Appleton-Whittell Research Ranch, Elgin, AZ.

Herpetofauna at the Appleton-Whittell Research Ranch. A rich diversity of amphibian and reptile species occurs at the Appleton-Whittell Research Ranch. The Research Ranch is an 8000-acre sanctuary for native biota and research facility in the semi-arid grasslands of southeastern Arizona, managed by the National Audubon Society. Since cattle were removed from the sanctuary in the late 1960s, nine species of amphibians and forty-two species of reptiles have been identified by staff and researchers within the preserve. Several species have not been seen in the recent years and may no longer occur on the Research Ranch. Ongoing efforts are underway to locate and document the presence of the herpetofauna. Our challenge into the future is to safeguard the continued existence of those that are still found and return native species that may have been extirpated.

Herpetofauna de la estación biológica Appleton-Whittell Research Ranch. La estación biológica Appleton-Whittell Research Ranch cuenta con una gran diversidad de especies de anfibios y reptiles. El centro de investigación es un santuario de 3,237 has de biota nativa en los pastizales semiáridos del sureste de Arizona a cargo de la Asociación Nacional Audubon. El personal y los investigadores visitantes han identificado 9 especies de anfibios y 42 especies de reptiles en la reserva desde que se desalojó el ganado a finales de la década de 1960. Varias especies no se han visto los últimos años y quizás ya no ocurren en la estación, por lo que se están llevando a cabo investigaciones para localizar y documentar la herpetofauna. El reto es proteger la existencia continua de las especies presentes y reintroducir especies nativas extirpadas.

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Climate change, megadroughts, and the North American monsoon. Climate change in the Southwest translates to changes in water availability, and records of past hydroclimate help us delineate the natural range of those changes. Past droughts are apparent in tree-ring based records and emerge from longer paleoclimate records as well. But do these droughts reflect changes in winter or summer moisture? This question is more than academic: as we move into a warmer world, we can expect generally drier winters and springs. But projections of future climate disagree

with respect to changes in the North American monsoon, and global models do not yet simulate this system well. Here we use paleoclimate records to explore how summer rainfall has responded during past climate regimes. In this talk I will describe new results from cave-based climate records that demonstrate how, over the past 7000 years, the monsoon has clearly weakened. This result is consistent with other monsoon systems globally and with climate model simulations. I will explore implications for future hydroclimate regimes in our Southwest region.

El cambio climático, megasequías y el monzón norteamericano. El cambio climático en el Suroeste Norteamericano induce cambios en la disponibilidad de agua, y los registros ambientales hidrológicos nos ayudan a delinear el rango natural de esos cambios. Las sequías anteriores son evidentes en los registros de anillos de árboles (dendroclimatología) y también emergen de registros de paleo-climas más largos. Pero estas sequías, ¿reflejan cambios en la humedad de invierno o verano? Esta pregunta es más que académica: conforme el mundo se vuelve más cálido podemos esperar inviernos y primaveras más secas. Pero las proyecciones del clima del futuro no coinciden en los cambios en el monzón norteamericano y los modelos mundiales todavía no simulan bien este sistema. Aquí usamos registros paleo climáticos para explorar como las lluvias de verano han respondido durante regímenes climáticos anteriores. En esta charla describiré nuevos resultados basados en registros climáticos de cuevas para mostrar como los últimos 7000 años, el monzón claramente se ha debilitado. Este resultado es consistente con otros sistemas monzónicos mundiales y con modelos climáticos. Exploraré implicaciones para regímenes hidroclimáticos futuros en nuestra región del Suroeste Norteamericano..

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Abundance and biomass of potential prey species for Mexican wolves (*Canis lupus baileyi*) in Sonora, México. Quantification of prey availability is a necessary step toward the successful implementation of a carnivore reintroduction program, under the assumption of a higher probability of success when a community is more diverse reflected on a lower biomass turnover, consequently creating a buffer for the newly introduced predator. The objective of this study was to assess the diversity, abundance and prey biomass potentially available to reintroduce Mexican wolves. We used camera traps between 2009 to 2011 in a 29,000 sq. km area, used a site-specific protocol to assess minimum number of prey and this was transformed to biomass by multiplying the weight times the density of a given species. We documented a total of 11 species, where white-tailed deer, Gould's Turkey and rock squirrels each contribute 50 kg/km². The remaining species although can be considered occasional or rare, contribute about 11.22 kg/km². Our results show that the area can support 25 to 30 Mexican wolves, with no negative effects toward prey species or livestock losses.

Diagnóstico de la biomasa disponible de presas útiles para el lobo mexicano (*Canis lupus baileyi*) en Sonora, México. Es necesario conocer la cantidad de presas disponibles para el éxito de un programa de reintroducción de carnívoros. Se asume que la probabilidad de éxito es más alta en una comunidad con mayor diversidad, dándole cierta protección al depredador recién introducido. El objetivo de este estudio fue evaluar la diversidad, abundancia y biomasa potencial de presas disponibles para la reintroducción del lobo mexicano. Se usaron cámaras trampa de 2009 a 2011 en un área de 29,000 km² y una metodología adaptada al sitio para evaluar la cantidad mínima de presas. La biomasa de cada especie se obtuvo al multiplicar el peso por la densidad de la especie. Se documentaron un total de 11 especies, donde el venado cola blanca, el guajolote silvestre y el ardillón contribuyen 50 kg/km² cada uno. Aunque el resto de las especies se consideran ocasionales cada una contribuye cerca de 11.22 kg/km². Estos resultados muestran que el área puede mantener de 25 a 30 lobos mexicanos sin afectar negativamente a las presas o al ganado.

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Preliminary standard for old-growth forests in the Sierra Madre Occidental. The Sierra Madre Occidental of México has temperate old-growth forests that have been seldom studied. They have been in decline since the advent of industrial logging, and currently lack protection unless included in protected areas. We collected structure and composition data in two temperate forests in Chihuahua, and based on this propose a regional preliminary old-growth standard. Our results showed that the basal area of old-growth forests was concentrated in diameter classes >40 cm, and that trees in diameter classes >60 cm were present in all the sampled sites. The minimum basal area was 25 m², dominated by species in the Pinaceae (*Pinus* and *Pseudotsuga*), but *Quercus* and broadleaved species contributed to overstory diversity. Snags and large logs were present. The understory was dominated by native species in the Asteraceae, Fabaceae, Poaceae and Lamiaceae. We found that indicator species that favor old-growth, such as the Thick-billed Parrot, can be useful in identifying sites and to promote their conservation. Since the information presented here was based on a dataset generated in two locations, it needs to be updated as more sites are explored, but meanwhile it can be used to negotiate protection of old-growth sites of northern México.

Estándar preliminar de bosques antiguos en la Sierra Madre Occidental. Los bosques antiguos de la Sierra Madre Occidental de México han sido poco estudiados. Su cobertura ha declinado desde el inicio de la tala industrializada, y solo se encuentran protegidos legalmente si están incluidos en áreas protegidas. Proponemos un estándar regional preliminar de bosques antiguos con base en datos de estructura y composición colectados en dos bosques templados de Chihuahua. Nuestros resultados indican que el área basal de los bosques antiguos se concentró en clases de diámetro >40 cm, y en todos los sitios de muestreo registramos árboles con diámetros >60 cm. El área basal mínima fue 25 m², dominada por especies de pináceas (*Pinus* y *Pseudotsuga*), mientras que *Quercus* y otras especies de latifoliadas contribuyeron a la diversidad del dosel.

En todos los sitios registramos la presencia de arbolado muerto en pie y troncos sobre el piso forestal. El estrato herbáceo y arbustivo estuvo dominado por especies nativas de Asteraceae, Fabaceae, Poaceae y Lamiaceae. El uso de especies indicadoras que favorecen las condiciones de hábitat de los bosques antiguos, como las guacamayas o cotorras serranas, es útil para la identificación de sitios y para promover su conservación. La información presentada se basó en datos generados en dos localidades, por lo que es importante actualizar este estándar a medida que se exploran otros sitios. Mientras tanto, se puede utilizar como medida temporal para proteger los bosques antiguos de las montañas del noroeste de México.

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Two old-growth forests from Chihuahua, México: composition, structure, age, and fire disturbance. We studied two high elevation (>2000 meters) old-growth forests in the Sierra Madre Occidental in Chihuahua, México: Mesa de las Guacamayas (MDG), located ~100 km from the U.S.-México border, and Parque Nacional Cascada de Basaseachi (PNCB), located in central Chihuahua. We measured the structure and composition of their overstory and understory, and collected increment cores and fire scars to create age reconstructions and fire histories. Both sites had high understory β -diversity, while overstory β -diversity was higher at PNCB. Understory species were all native at MDG, and we only collected one exotic at PNCB. Forests in the two sites had snags >40 cm and logs on the forest floor, as well as trees with diameters >60 cm. The oldest trees at the two sites established in the mid 1700s, and their fire histories indicate that frequent fires that burn at least once every decade are part of their disturbance regimes. Both sites have high conservation value and are included in protected areas, while MDG is the northernmost known nesting site for Thick-billed Parrots. Conservation of these forests should incorporate integrated fire management, and structural and compositional complexity should be maintained in order to ensure habitat quality.

Dos bosques antiguos de Chihuahua, México: composición, estructura, edad e historia de incendios. Estudiamos dos bosques antiguos en elevaciones >2000 metros en la Sierra Madre Occidental de Chihuahua, México: Mesa de las Guacamayas (MDG), ubicada a ~100 km de la frontera México-E.U., y el Parque Nacional Cascada de Basaseachi (PNCB), ubicado en el centro del estado. Medimos la estructura y composición del dosel y el estrato herbáceo y arbustivo, y colectamos cilindros de incremento y cicatrices de incendios para crear reconstrucciones de edad e historias de incendios. La diversidad β del estrato herbáceo y arbustivo fue alta en los dos sitios, mientras que la diversidad β del dosel fue más alta en PNCB. Todas las especies del estrato herbáceo y arbustivo colectadas en MDG fueron identificadas como nativas, y solo una de nuestras colectas en PNCB fue identificada como exótica. Los bosques en los dos sitios presentaron árboles muertos en pie con diámetros >40 cm y troncos en el piso forestal, así como árboles con diámetros >60 cm. Los árboles más antiguos en los dos sitios se establecieron a mediados del siglo XVIII, y sus historias de incendios indican que los regímenes de perturbación de ambos sitios presentan incendios frecuentes, al menos una vez cada década. Ambos sitios son de alto valor para la conservación y están incluidos en áreas protegidas, y MDG es el sitio más norteño de anidación de la guacamaya o cotorra serrana. La conservación de estos bosques debe de incorporar manejo integrado del fuego, y la complejidad estructural y de la composición debe de mantenerse con el fin de asegurar la calidad del hábitat.

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Temporal patterns in species flowering can inform long-term plant monitoring. The flowering patterns of plants of the Finger Rock trail, located in the Santa Catalina Mountains of southern Arizona, have been very carefully documented on an approximately weekly basis for nearly three decades. These observations, made along a gradient encompassing more than 4,000 ft in elevation, have yielded key insights into climatic flowering cues as well as range shifts among particular species. These long-term observations of flowering plant phenology have also revealed that the regularity with which plant species flower from year to year is highly variable. We implemented a clustering algorithm to elucidate recurrent temporal flowering patterns in species. Several patterns emerged, and these patterns are consistent with plant life forms and the water use strategies they employ as well as native/non-native status. The findings of this analysis are valuable for guiding species selection for long-term monitoring efforts.

Uso de los patrones temporales de floración en el monitoreo a largo plazo de plantas. La floración de plantas en la vereda Finger Rock, de la Sierra Santa Catalina del sur de Arizona, se documentó en detalle casi semanalmente durante tres décadas. Las observaciones en un gradiente altitudinal de más de 1220 m, arrojaron información clave sobre estímulos climáticos de floración y cambios de distribución de ciertas especies. Estas observaciones de la fenología de floración, hechas por muchos años, también mostraron que la regularidad con que las especies florecen año tras año es muy variable. Se implementó un algoritmo de ordenamiento para esclarecer los patrones de floración temporales recurrentes. Se obtuvieron varios patrones consistentes con las formas de vida de las plantas y sus estrategias de uso de agua, y también su estatus de nativa o introducida. Los resultados de estos análisis son muy útiles en la selección de especies para el monitoreo a largo plazo.

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Agricultural field restoration utilizing native grasses; Lower San Pedro River watershed. Agricultural Field Restoration Utilizing Native Grasses; Lower San Pedro River Watershed is a case study documenting results from three representative projects. The projects are partnerships between The Nature Conservancy and individual property owners. The study documents the challenges with the process of agricultural field restoration, the methods utilized for change over to native grasses at the specific sites and the results. The suite of potential benefits of grass cropping projects is numerous and reviewed within the study analysis. Potential benefits include; reduction in water and power usage, allow businesses to be more sustainable and resilient to drought in the future, restore the integrity of the riparian habitat and address the affects of climate change. The longer-term outcomes we hope to see from sharing this research at the conference are; an interest in change over to native grasses, an increased market in native grass hay and the development of seed banking for rehabilitation projects. One of the goals of the research is to inspire others to try to answer some of the questions within the framework of the process of the restoration projects. The research provides documentation to support further study and has utility for different audiences.

Restauración de campos agrícolas mediante el uso de zacates nativos en la cuenca baja del río San Pedro. La restauración de campos agrícolas utilizando zacates nativos en la cuenca baja del río San Pedro es un estudio de caso que documenta resultados de tres proyectos representativos. El proyecto es una colaboración entre la organización The Nature Conservancy y propietarios. El estudio documenta los retos en el proceso de restauración de campos agrícolas, los métodos usados para el cambio a zacates nativos y los resultados. La variedad de beneficios potenciales del cultivo de zacates nativos son numerosos y se examinan en el análisis del estudio. Los beneficios incluyen la disminución en el uso de agua y electricidad, durabilidad y resistencia a futuras sequías, restauración de los hábitats ribereños y adaptación al cambio climático. Al presentar este trabajo se espera: un interés en el cultivo de zacates nativos, aumento del mercado de forraje de zacates nativos y la creación de un banco de semillas para proyectos de restauración. Una de las metas de este proyecto es inspirar para buscar respuestas a los problemas que se presentan en los proyectos de restauración. Esta investigación tiene la documentación necesaria para apoyar estudios adicionales útiles a diferentes audiencias.

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A Late Quaternary Brown Bear (*Ursinae: Ursus cf. arctos*) from a cave in the Huachuca Mountains, Arizona. In 2008 one of the authors (SW) discovered the fragmentary cranium of a bear, loose on the floor of a cave at about 2270 m elevation near the crest of the Huachuca Mountains. In 2009 we revisited the cave to examine the specimen in order to identify the species. We photographed and measured the main pieces and left them in the cave. The skull is from an adult, possibly male with prominent sagittal crest. Bears are highly variable morphologically and their remains are difficult to identify. Many North American black bears were larger in the late Pleistocene and underwent a size reduction in the Holocene. The morphological features and measurements of the present cranium are somewhat equivocal, but most available features indicate a brown bear, *Ursus cf. arctos*. Some parts are encrusted with carbonate and could be better examined after collection and preparation as well as comparison with late Pleistocene brown and black bears. Based on its state of preservation, the cranium possibly represents a late Pleistocene occurrence, which could be determined by radiometric dating. There is no previous fossil record of *U. arctos* in the Sky Islands, nor in the rest of Arizona, New Mexico, Chihuahua, or Sonora.

Registro de oso pardo (*Ursinae: Ursus cf. arctos*) del Cuaternario tardío de una cueva en la Sierra Huachuca, Arizona. En 2008 uno de los autores (SW) encontró el fragmento de un cráneo de oso en el suelo de una cueva a 2270 m de elevación, cerca de la cumbre de la Sierra Huachuca. En 2009 se visitó de nuevo la cueva para examinar el ejemplar e identificar la especie. Se tomaron fotografías y medidas de las partes principales sin removerse de la cueva. El cráneo es de un adulto, posiblemente macho con una marcada cresta sagital. Los osos tienen una morfología muy variable y es muy difícil identificar sus restos óseos. Muchos osos negros de América del Norte fueron más grandes a finales del Pleistoceno pero su tamaño se redujo en el Holoceno. Las medidas y características morfológicas de este cráneo son un poco ambiguas, sin embargo indican que es un oso pardo *Ursus cf. arctos*. Algunas partes están incrustadas con carbonato y podrían examinarse con más detalle después de recolectarse, prepararse y compararse con osos pardos y negros de finales del Pleistoceno. Según su estado de preservación, es posible que el cráneo represente un registro del Pleistoceno lo que podría determinarse por el método del carbono 14. No hay registros previos de fósiles de *U. arctos* de las Islas Serranas de Arizona, Nuevo México, Chihuahua o Sonora.

DEAN, VIRGINIA. Appleton-Whittell Research Ranch of the National Audubon Society, Elgin, AZ.

Biodiversity database at the Appleton-Whittell Research Ranch. The Appleton-Whittell Research Ranch provides the location, resources, and opportunity for natural-history research projects in ungrazed, unimproved grasslands of southeastern Arizona, USA. At ranch headquarters, research since 1968 is archived as hard-copy pages of published and unpublished documents, conference posters, electronic files of data and photographs, specimen collections, and species checklists for visitors. A recent addition to the archiving methods is an Excel[®] database of all plants or animals that have been documented as occurring on the Research Ranch. Each record includes several fields that are filled in whenever the information is available. These include order, family, genus, and species names; date of the sighting; location by GPS, landmark, or local place-name; type of habitat; life stage of the specimen; names and titles of the observer and species identifier; observed associated species and relationships; and photographs. A comment column or additional separate columns contain other interesting observed data, e.g., weather

conditions, time of day, activity, health, size, color, unique attributes. The database consolidates local historical data that can be updated and used by future researchers in their reports.

Base de datos de la Estación Biológica Appleton-Whittell. La Estación Biológica Appleton-Whittell proporciona la ubicación, recursos y oportunidades para proyectos de investigación en historia natural en las praderas sin pastoreo, ni mejoradas del sureste de Arizona, E.U.. En sus instalaciones, desde 1968 se archivan copias de los documentos publicados y sin publicar, carteles en congresos, archivos electrónicos de datos y fotografías, colecciones de especímenes y listados de especies, disponibles para visitantes. Recientemente se creó una base de datos de Excel[®] de todos los animales y plantas registrados en la Estación Biológica. Cada registro cuenta con varios campos que se capturan con la información disponible. Éstos incluyen orden, familia, género y especie; fecha de observación; ubicación con GPS, puntos de referencias o nombre local del lugar; tipo de hábitat; forma de vida; nombre y título del observador y el identificador de la especie; especies asociadas observadas y relaciones; y fotografías. Columnas adicionales son para comentarios u otros datos interesantes observados, ej. condiciones del tiempo, hora, actividad, salud, tamaño, color, y características únicas. La base de datos consolida los datos locales históricos que pueden ser actualizados y usados por futuros investigadores en sus estudios.

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Vascular plants of the riparian habitats of El Aribabi Ranch, Municipio de Ímuris, Sonora, Mexico. The state of Sonora, with an area of 184,934 km², relies on an inventory of vascular plants including as many as 3,659 taxa, but the region defined as 'The Borderlands' alone has an inventory of 1,706 taxa. The aim of the current work is to increase knowledge of the plants of the Borderlands as well as to get to know the floral diversity of its riparian habitats; the latter through a study in a representative zone (El Aribabi Ranch), chosen for its proximity to the border and the convergence of different biotic communities. The inventory of documented plants for the riparian habitats of El Aribabi Ranch adds to a total of 354 taxa, distributed in 78 families and 245 genera; with respect to the number of species, the most well represented families were Asteraceae (57), Poaceae (31) and Fabaceae (31). The plants present in the riparian habitats of El Aribabi Ranch represent 77% of the total number of plants of the ranch, and the plant composition seems to be similar to the flora of other rivers in the region such as the San Pedro (Cananea) and the Santa Cruz River (Santa Cruz).

Plantas vasculares de hábitats ribereños del rancho El Aribabi, municipio de Ímuris, Sonora, México. El estado de Sonora, con una superficie de 184 934 km², cuenta con un inventario de plantas vasculares que llega a 3,659 taxones, pero solo la región definida como La Frontera presenta un inventario de 1,706 taxones. La finalidad del presente trabajo es incrementar el conocimiento sobre las plantas de La Frontera así como conocer la diversidad florística de sus hábitats ribereños; esto último a través de un estudio en una zona representativa (rancho El Aribabi), elegida por su cercanía a la frontera y la convergencia de diferentes comunidades bióticas. El inventario de plantas registrado para los hábitats ribereños del rancho El Aribabi suma un total de 354 taxones, distribuidos en 78 familias y 245 géneros, en cuanto al número de especies, las familias mayormente representadas fueron Asteraceae (57), Poaceae (31) y Fabaceae (31). Las plantas presentes en los hábitats ribereños del Aribabi representan un 77% del número total de plantas para el rancho, y la composición florística parece presentar similitud con las floras de otros ríos de la región como son el río San Pedro (Cananea) y el río Santa Cruz (Santa Cruz).

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Database Workshop: Documenting the biodiversity of the Madrean Archipelago. The Madrean Archipelago Biodiversity Assessment (MABA) of Sky Island Alliance in Tucson, Arizona, is an ambitious project to document the distributions of all species of animals and plants in the Madrean Archipelago, focusing particularly on northeastern Sonora and northwestern Chihuahua. The information gathered is made available through MABA's online database (madrean.org). The sources of these records are museum collections, herbaria, scientific literature, other databases, observations, and field notes. Many observations come from MABA expeditions to isolated mountain ranges in northeastern Sonora involving taxonomic specialists, professors, students, and others from universities in Arizona and Sonora; personnel from Mexican agencies like CEDES and CONANP; and other participants. The databases for flora and fauna are separate; fauna has over 100,000 records and flora has more than 500,000 records. This workshop is an opportunity to better understand the status of digital plant and animal records in the region and learn to use the database. The MABA database has a complex structure, allowing searches for scientific records by name, location, collector, geographical area, etc. Records in the database can be displayed as detailed specimen records, taxonomic lists, or interactive Google maps. Species lists and identification keys for areas of interest can be created. The database is a powerful resource for researchers, conservationists, and natural history enthusiasts working in the Madrean Archipelago.

Taller: Documentación de la Biodiversidad del Archipiélago Madreño. El Programa de Evaluación de la Biodiversidad del Archipiélago Madreño (MABA en inglés) de Sky Island Alliance en Tucson, Arizona, es un proyecto ambicioso para documentar las distribuciones de todas las especies de animales y plantas en la región de las Islas Serranas, enfocado particularmente en el noreste de Sonora y noroeste de Chihuahua. Toda la información se captura en la base de datos MABA, accesible en línea (madrean.org). Las fuentes de registros son colecciones en museos y herbarios, literatura científica, otras bases de datos, observaciones y apuntes de campo. El proyecto MABA realiza expediciones a sierras aisladas en Sonora con especialistas de distintos taxones, profesores, estudiantes de universidades en Sonora y Arizona; personal de oficinas de gobierno como CEDES y CONANP; y otros participantes. Las bases de datos de fauna y flora están separadas; fauna tiene más de 100,000 registros y flora tiene más de 500,000 registros. Este taller es una oportunidad para entender mejor el estado de registros digitales de plantas

y animales en la región y el uso de la base de datos. La base de datos MABA tiene una estructura compleja. Se pueden buscar registros por nombres científicos, localidades, colectores, o áreas geográficas. Los datos se pueden obtener como registros detallados, listas taxonómicas o mapas interactivos de Google. Se pueden crear listas y claves de identificación de especies por áreas de interés. La base de datos de MABA es un recurso poderoso para investigadores, conservacionistas, y entusiastas de historia natural trabajando en el Archipiélago Madrense.

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Effects of temperature and precipitation on annual variation in breeding phenology of Red-faced Warblers in the Santa Catalina Mountains. Increases in ambient temperatures have caused advances in breeding date for birds in North America and Europe. However, empirical data is lacking for evaluating the potential effects of climate change on breeding phenology of birds in the Madren region where changes in precipitation may be more important than changes in temperature. We examined the effects of temperature and precipitation on breeding phenology of red-faced warblers over a 10-year period in the Santa Catalina Mountains. May precipitation was negatively associated with breeding date ($t = -4.89, p = <0.001$), but annual variation in temperature had no effect. Additionally, we found a positive relationship between nest initiation date and year, suggesting that red-faced warblers have initiated nesting later in the season over the past ten years ($t = 6.20, p = <0.001$). These results are opposite to those reported in many systems, where results have shown nests are initiated earlier over time. This suggests that in our system, variation in precipitation may be a more important predictor of phenological variation than temperature; birds delay breeding in dry years.

Efectos de la temperatura y precipitación en la variación anual de la fenología de reproducción del chipe cara roja en la Sierra Santa Catalina. Los aumentos de la temperatura ambiental han causado adelantos de la fecha de reproducción de las aves en Norteamérica y Europa. Sin embargo, los datos empíricos no son suficientes para evaluar los efectos del cambio climático en la fenología de las aves en la región Madrense donde los cambios en precipitación podrían ser más importantes que los cambios en temperatura. Analizamos el efecto de la temperatura y la precipitación en la fenología de la reproducción del chipe cara roja por un periodo de 10 años en la Sierra Santa Catalina. La precipitación de mayo tuvo un efecto negativo en la fecha de reproducción ($t = -4.89, p = <0.001$), pero la variación anual de temperatura no impactó. Se encontró una relación positiva entre la fecha de inicio del nido y el año, lo cual sugiere que el chipe cara roja ha iniciado la anidación más tarde en los últimos 10 años ($t = 6.20, p = <0.001$). Estos resultados son opuestos a los encontrados en muchos sistemas, donde los resultados han mostrado que los nidos se inician más temprano al pasar los años. Esto sugiere que en nuestro sistema, la variación en precipitación puede ser un vaticinador de la variación de la fenología más importante que la temperatura; las aves demoran la reproducción en años secos.

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Gila River Basin Native Fishes Conservation Program. The Central Arizona Project Gila River Basin Native Fishes Conservation Program (CAP Program) conserves native fishes and manages against nonnative fishes after several Endangered Species Act consultations between the Bureau of Reclamation and the U.S. Fish and Wildlife Service on CAP water transfers to the Gila River basin. Populations of some Gila River native fish species are extremely rare and appear on the verge of extirpation. The CAP Program funds conservation actions for five priority fishes, and other native fishes. A high priority of the CAP Program is to replicate federally listed species into suitable, protected streams and repatriate populations of listed and other native fishes into them. Also funded are the control and eradication of non-native fishes. Over \$6 million has been allocated; and Reclamation will fund about \$10.5 million to the Service the next 20 years. One half the funding is for native fish recovery actions, and one half for non-native actions. Projects are jointly agreed upon by Reclamation and the Service in consultation with the Arizona and New Mexico Game and Fish Departments. Numerous conservation and recovery projects have been implemented to date, and will be summarized.

Programa de conservación de peces nativos de la cuenca del río Gila. El programa de conservación de peces nativos de la cuenca del río Gila del Proyecto Arizona Centro (programa CAP por sus siglas en inglés) conserva los peces nativos y controla peces exóticos. Este acuerdo se tomó después de que el Servicio Federal de Pesca y Vida Silvestre de E.U. (US FWS por sus siglas en inglés) y la Oficina de Rehabilitación analizaron la Ley de Especies en Peligro de Extinción y el traspaso de agua CAP a la cuenca del río Gila. Las poblaciones de algunas especies de peces nativos del río Gila son bastante raras y están en grave peligro de ser extirpadas. El programa CAP apoya proyectos de conservación de cinco especies de peces prioritarios y otros peces nativos. Para el programa CAP es de suma importancia reproducir y reintroducir especies con categoría de riesgo en la norma federal y otros peces nativos en ríos adecuados y protegidos. También financia el control y erradicación de peces exóticos. Se han destinado más de \$6 millones de dólares y la Oficina de Rehabilitación destinará cerca de \$10.5 millones al Servicio (US FWS) los próximos 20 años. La mitad del financiamiento es para el rescate de peces nativos y la otra mitad para el control de peces exóticos. Los proyectos son aprobados tanto por la Oficina de Rehabilitación y el Servicio (US FWS) con asesoramiento del Departamento de Caza y Pesca de Arizona y Nuevo México. Se presentará un resumen de los numerosos proyectos de conservación y rescate realizados.

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Gila opminnow interactions with western mosquitofish: an update. It has long been known, and thoroughly documented the western mosquitofish (*Gambusia affinis*), has major deleterious effects on individual Gila topminnow (*Poeciliopsis occidentalis*) and their populations. It has been many years since information on this negative impact has been updated. Therefore, I will list and discuss additional examples where mosquitofish have impacted topminnow. In addition, it appears that climate change and long-term drought have a synergistic and negative affect on this relationship. Since the last publications detailing the loss of Gila topminnow populations to mosquitofish, two natural topminnow populations have been lost in the Santa Cruz River basin: Redrock Canyon and Sheehy Spring. Drought and climate change likely assisted mosquitofish with extirpating these two natural populations. Lastly, climate change may facilitate expanded mosquito populations or expanded mosquito seasons within the range of the Gila topminnow. Current literature discusses that existing tropical and subtropical diseases, or novel diseases, may move north into Gila topminnow range. If mosquitoes and diseases they carry become more prevalent, the desire and demand for vector control, particularly mosquitofish, will increase. I will discuss tools and programs such as Habitat Conservation Plans and Safe Harbor Agreements that can allow the use of native fish for vector control.

Interacciones del guatopote del Gila con el guayacón mosquito: información reciente. El efecto nocivo del guayacón mosquito (*Gambusia affinis*) sobre el guatopote del Gila (*Poeciliopsis occidentalis*) y sus poblaciones se conoce desde hace tiempo y se ha documentado en detalle. Han pasado muchos años desde la última actualización sobre este impacto negativo, por lo que se enumerará y analizarán ejemplos adicionales donde el guayacón mosquito impactó al guatopote del Gila. Además parece que el cambio climático y la sequía prolongada tienen un impacto sinérgico y negativo en esta relación. Desde la última publicación donde se describe la pérdida de poblaciones de guatopote del Gila por guayacón mosquito, otras dos poblaciones naturales de guatopote han desaparecido de la cuenca del río Santa Cruz: Redrock Canyon y Sheehy Spring. Es probable que la sequía y el cambio climático contribuyeron con el guayacón mosquito a extirpar estas dos poblaciones naturales. Por último, el cambio climático quizás ayude a aumentar las poblaciones del guayacón mosquito o alargue su temporada en el área de distribución del guatopote del Gila. Según la literatura actual las enfermedades tropicales, subtropicales y raras podrían extenderse al norte en el área del guatopote del Gila. Si los mosquitos y las enfermedades que transmiten se extienden, la necesidad y demanda por control del vector, en especial el guayacón mosquito, aumentará. Se analizarán métodos y programas como los Planes de Conservación del Hábitat y Compromiso de Propietarios con las Especies en Peligro de Extinción que pueden permitir el uso de peces nativos para el control de vectores.

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Hidden biodiversity of Sky Island arthropods. Tenebrionid and carabid beetles are conspicuous members of the southwest Sky Island invertebrate community and can be found across a range of habitats, including the oak woodlands and pine forests capping many of the region's mountains. Beetles living within these high-elevation habitats typically occur on more than one mountain, though populations on different mountains have likely been isolated from one another since at least the end of the Wisconsin Glacial Period (10,000 ya). We combine traditional taxonomy and molecular phylogenetics to show that for many species, geographic isolation has restricted dispersal between mountains, leading to the establishment of independent evolutionary lineages. The prevalence of genetic isolation in the species examined highlights the unique diversity contained within the Sky Islands, and the threat climate change poses to regional biodiversity.

Biodiversidad de artrópodos escondida en las Islas Serranas. Los escarabajos tenebriónidos y carábidos son notorios miembros de los invertebrados de las Islas Serranas del Suroeste Norteamericano y se pueden encontrar en un amplio rango de hábitats, incluso en los encinales y pinales de la zona montañosa. Los escarabajos que habitan este rango de elevación típicamente se distribuyen en más de una montaña, sin embargo las poblaciones de diferentes montañas se aislaron una de otra desde finales del periodo glacial Wisconsin (10,000 años). Se combinaron técnicas taxonómicas tradicionales y filogenética molecular, para demostrar que el aislamiento geográfico ha limitado la dispersión entre montañas, generando linajes evolutivos independientes. El predominio de la separación genética de las especies resalta la diversidad única en las Islas Serranas, y la amenaza que el cambio climático representa.

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A biogeographic perspective of speciation among desert tortoises in the genus *Gopherus*. The distribution of organisms we observe in the Sonoran Desert has been sculpted by the enduring processes of time, climate, and adaptation. One of these species is Morafka's desert tortoise, *Gopherus morafkai* and we are applying a genomic approach to better understand what evolutionary processes were responsible for shaping diversity in this species. The "Sonoran" desert tortoise exhibits a continuum of genetic similarity spanning 850 km of Sonoran desertscrub, from Hermosillo, Sonora to Kingman, Arizona. However, at the ecotone between desertscrub and thornscrub we identify a distinct, "Sinaloan" lineage that suggests a more complex evolutionary story for this species. By using multiple loci from throughout the tortoise genome, we aim to determine if divergence between these lineages occurred in allopatry, or if there are signatures of past or current introgression. This international, collaborative project will assist state and federal agencies in developing management strategies that best preserve the evolutionary

potential of the desert tortoise. Ultimately, understanding the evolutionary history of desert tortoises will not only clarify the forces that have driven the divergence in this group, but it will also contribute to our knowledge of the biogeographic history of the southwestern deserts and how diversity is maintained within them.

Una perspectiva biogeográfica de especiación de la tortuga del desierto en el género *Gopherus*. La distribución de organismos que observamos en el Desierto Sonorense ha sido esculpida por los procesos perdurables del tiempo, clima y adaptación. Una de estas especies es la tortuga del desierto Morafka (*Gopherus morafkai*) e hicimos un estudio genómico para comprender mejor cuales procesos evolucionarios son responsables de configurar la diversidad de esta especie. La tortuga del desierto “Sonorense” exhibe un continuo de semejanza genética abarcando 850 km de matorral del Desierto Sonorense, desde Hermosillo, Sonora a Kingman, Arizona. Sin embargo, en el ecotono entre matorral del desierto y matorral espinoso, identificamos un linaje “Sinaloense” distinto, el cual sugiere una historia de evolución más compleja para esta especie. Por medio del uso de múltiples loci de todo el genoma de la tortuga, estamos tratando de determinar si la divergencia entre estos linajes ocurrió en una especiación alopatrica o si son indicaciones de introgresiones del pasado o actuales. Este proyecto de colaboración internacional servirá a las agencias estatales y federales en la planeación estratégica de manejo para conservar el potencial evolucionario de la tortuga del desierto. Al final el comprender la historia de la evolución de la tortuga del desierto no sólo ayudará a entender las fuerzas que han impulsado la divergencia en este grupo, sino que también contribuirá a nuestro conocimiento de la historia biogeográfica de los desiertos del suroeste y como se sostiene la diversidad en ellos.

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Phenology as a tool for natural resource management and climate change adaptation in the Southwest and beyond. Phenology is widely accepted as a robust ecological indicator of the impacts of climate change on plants, animals and people. Climate-induced changes in phenology have been linked to shifts in the timing of allergy seasons and cultural festivals, increases in wildfire activity and pest outbreaks, shifts in species distributions, declines in the abundance of native species, the spread of invasive species, and changes in carbon cycling in forests. The breadth of these impacts highlights the potential for phenology to inform management and policy-decisions across sectors. Here, we focus on using phenology as a tool for natural resource management. We address the importance of climate-smart monitoring in an adaptive management framework and show how phenology data can and have been used in species vulnerability assessments. In turn, we discuss how these efforts can inform management planning and implementation, such as in identifying on-the-ground adaptation actions related to invasive species, fire, and biodiversity conservation. Finally, we highlight how a new, off-the-shelf phenology monitoring program, *Nature's Notebook*, is both operationalizing systematic data collection at protected areas across the United States and is cultivating the public's natural and climate science literacy by using a participatory citizen science approach.

Aplicación de la fenología en el manejo de recursos naturales y la adaptación al cambio climático en el Suroeste Norteamericano. La fenología se reconoce como un fuerte indicador ecológico del impacto del cambio climático en las plantas, animales y la gente. Cambios inducidos por el clima en la fenología se han relacionado con cambios en el inicio de temporadas de alergias y festivales culturales, el incremento en incendios forestales y el brote de plagas, cambio en la distribución de especies, disminución de especies nativas, propagación de especies invasoras, y cambios en el ciclo del carbono de los bosques. El alcance de estos impactos resalta la importancia de la fenología en el manejo y decisiones en diferentes sectores. En este estudio nos enfocamos en la aplicación de la fenología en el manejo de recursos naturales. Abordamos la importancia del monitoreo eficiente y el manejo adaptable y demostramos como los datos de fenología pueden y son usados en la evaluación de vulnerabilidad de especies. Asimismo se analiza como esta recopilación de datos puede ser útil en el manejo, como el identificar adaptaciones relacionadas con especies invasoras, incendios, y conservación de la biodiversidad. Finalmente, se resalta cómo un programa nuevo y práctico de monitoreo de fenología *Nature's Notebook* (Libreta de la Naturaleza), está basado en operación y sistemática para la colección de datos en áreas protegidas de Estados Unidos y está influenciando la literatura mediante el uso de metodologías participativas de la ciudadanía con un enfoque científico.

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Effects of landscape structure on the abundance of black bear (*Ursus americanus*) in the Sky Islands of Sonora, México. Landscape characteristics can be important predictors to understand species presence and abundance. Recently, several studies have highlighted the importance of carnivore management at a landscape level because of their large area requirements. The fundamental unit of any given landscape is the patch, where size and shape are the two main characteristics. Patch size is correlated to the quantity of resources, while shape to external effects. Between the years 2009-2011 we estimated abundance of black bear (*Ursus americanus*) in the sky islands of northeastern Sonora using trap cameras. Patches were defined from the species point of view using the lowest registered altitude obtain during the samples and cover types that bears preferred in this part of their distribution. Abundance of bears was highly variable across study sites, ranging from 3 to 34 individuals. We performed a generalized linear model that shows a significant relationship between abundance and patch features ($p=0.05$), however we believe that others factors may be affecting them, such as anthropogenic factors. As black bears are considered endangered in México, there is an urgent need to develop efficient management conservation strategies.

Efectos de la estructura del paisaje en la abundancia del oso negro (*Ursus americanus*) en las Islas Serranas de Sonora, México. Las características del paisaje pueden ser indicadores importantes de la presencia y abundancia de especies. Estudios recientes resaltan la importancia del manejo de carnívoros a nivel paisaje por su rango de distribución. La unidad fundamental del paisaje es el parche, las características más importantes son tamaño y forma. El tamaño del parche está relacionado con la cantidad de recursos, mientras que la forma está ligada a efectos externos. Entre 2009-2011 estimamos la abundancia del oso negro (*Ursus ameriacnus*) en las islas serranas del noreste de Sonora empleando cámaras trampa. Los parches fueron definidos empleando la distribución de la especie, se registró la altitud más baja y el tipo de vegetación donde se distribuye. La abundancia de osos fue muy variable, de 3 a 34 individuos por sitio. Generamos un modelo lineal general que demuestra la relación entre abundancia y parches ($p=0.05$), sin embargo creemos que hay otros factores influyendo los resultados como factores antropogénicos. Dada la situación de peligro del oso negro en México, existe una necesidad urgente de desarrollar estrategias de manejo y conservación.

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The plot thickens: Volunteers, organizations, buffelgrass control and habitat restoration in the Ironwood Forest National Monument, Arizona. Arizona Native Plant Society (AZNPS) volunteers have partnered with numerous organizations to effect measurable invasive plant removal and native vegetation restoration on an 18-acre, heavily disturbed and buffelgrass (*Pennisetum ciliare*)-infested site in the Waterman Mountains in Ironwood Forest National Monument. In 2010 the Bureau of Land Management performed land reshaping to improve water retention and minimize erosion. Volunteers planted native woody species on the worked ground and repeatedly sprayed buffelgrass as it germinated. By 2011 over 66 different native plant species had emerged including several thousand native woody plants, some from the existing seed bank and some from seeds planted by volunteers. Due to poor emergence on about three acres, volunteers continue to install rock *media-lunas* and manure-amended planting holes. Annual transect data and photo-point images are gathered to track restoration progress. The long-term objective is to restore this site to a natural foothills paloverde upland landscape.

Voluntarios, organizaciones, control de zacate buffel y restauración de hábitats en el área protegida Ironwood Forest National Monument, Arizona, la historia se complica. Voluntarios de la AZNPS (Arizona Natve Plant Society) han colaborado con numerosas organizaciones para lograr niveles notables de control de plantas invasoras y restaurar la flora nativa en un sitio de 7 hectáreas bastante alterado e infestado por zacate buffel (*Pennisetum ciliare*) en la Sierra Waterman de Ironwood Forest National Monument. La Oficina de Administración de Tierras (BLM) en 2010 reconfiguró la topografía para mejorar la retención de agua y disminuir la erosión. Voluntarios plantaron especies leñosas nativas en la tierra reconfigurada y fumigaron, en repetidas ocasiones, el buffel recién germinado. Para 2011, más de 66 especies distintas de plantas nativas habían brotado, incluso varios miles de plantas leñosas nativas, algunas de la reserva natural de semillas en el suelo y otras de semillas sembradas por los voluntarios. Debido a escasa germinación en aproximadamente una hectárea y media, los voluntarios siguieron instalando medias-lunas de piedra y hoyos para plantar abonadas con estiércol. Se archivan los datos anuales de transectos e imágenes de puntos fotográficos para monitorear el avance de la restauración. El objetivo a largo plazo es de restaurar este sitio a un paisaje natural de palo verde.

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Are Sky Island ecosystems approaching tipping points? Severe large-scale disturbances can trigger abrupt ecosystem transitions into novel configurations. These new configurations can be resilient in their new state and resistant to return to pre-disturbance conditions. Such abrupt transitions are predicted to become more common under conditions of altered climate, in which the regeneration niche and assembly rules for species and community responses may preclude a simple linear return to the pre-disturbance distribution. In addition to ecological effects, these transitions also include potentially persistent alterations to geomorphic, soil, hydrological, and biogeochemical systems. Large-scale, severe disturbance events appear to play a triggering role that releases accumulated tension between bioclimatic envelopes and ecological communities. In several Sky Island mountain ranges, including the Pinalenos, Huachuca, and Chiricahuas, recent large-scale fires may be setting the stage for such threshold behavior. Fire regimes in other landscapes, particularly the Gila Wilderness, appear to be less departed from the natural range of variability and hence more resilient even during relatively severe fire seasons. Ecosystem transitions may be viewed as dysfunctional system behavior, or as a reflection of system adaptation to novel conditions. We explore both scientific and management implications of these ecosystem dynamics.

¿Están los ecosistemas de las Islas Serranas alcanzando momentos críticos? Los desastres a gran escala pueden detonar abruptas transiciones en el ecosistema ocasionando nuevas configuraciones. Estas nuevas configuraciones pueden estar mejor adaptadas a su nuevo estado y resistentes para regresar a las condiciones previas. Estos cambios abruptos serán más comunes en condiciones del cambio climático, en donde la regeneración de nichos y las reglas de asociación durante la reacción de especies y comunidades impedirá un regreso lineal al estado previo al disturbio. Aunado a los efectos ecológicos, estas transiciones incluyen alteraciones potenciales y persistentes a la geomorfología, suelo, hidrología y biogeoquímica del sistema. Disturbios severos y de gran escala juegan un papel detonador que libera la tensión acumulada entre los factores bioclimáticos y ecológicos en las comunidades. En distintas cordilleras de las Islas Serranas como Pinalenos, Huachuca y Chiricahuas, incendios recientes de gran escala probablemente estén favoreciendo que se llegue al umbral crítico. Los regímenes de fuego en otros lugares, en especial el área natural Gila, parecen estar más acorde con el rango natural de variabilidad y por tanto su resistencia es mayor incluso bajo condiciones severas de incendios. Ecosistemas en transición pueden ser percibidos como sistemas disfuncionales, o como el reflejo de la adaptación del sistema a nuevas condiciones. Exploramos las implicaciones científicas y de manejo de esta dinámica de los ecosistemas.

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Wildlife surveys and monitoring with the use of remote camera traps in the Greater Oak Flat Watershed near Superior, Arizona. In September, 2011 we initiated a two-year camera survey in the Greater Oak Flat Watershed near Superior, Arizona. Our survey area covers a total of 25 square miles (6,475 Hectares). The area surveyed is primarily a mixing zone of upper Sonoran Desert and interior chaparral, with some influences from the Madrean vegetation community ranging from 3,800 feet to 4,800 feet of elevation. Ten cameras were deployed in early October of 2011 and information gathered and analyzed from that date to April 2012. We located cameras primarily in riparian drainages, occupying a representative sampling of the total area. Locations were chosen as logical wildlife corridors to obtain a representative sampling of wildlife while allowing relatively easy access to cameras for data collection. To date, we have identified 11 mammalian species, including bobcat (*Lynx rufus*), ringtail (*Bassariscus astutus*), and coati (*Nasua narica*).

Evaluación y monitoreo de fauna con cámaras remotas del área de Oak Flat cerca de Superior, Arizona. En septiembre de 2011 iniciamos un proyecto de 2 años de evaluación de fauna silvestre con cámaras remotas en el área Greater Oak Flat Watershed cerca de Superior, Arizona. Nuestra evaluación abarca un área de 6,475 hectáreas. La zona de monitoreo es principalmente una mezcla de Desierto Sonorense alto y chaparral interior, con algunas influencias de vegetación Madreña en elevaciones de 1,200 a 1,500 metros. Diez cámaras fueron instaladas a principios de octubre de 2011 y la información recopilada y analizada cubre hasta abril de 2012. Las cámaras se ubicaron principalmente en drenajes ribereños, con una muestra representativa de la superficie total. Las localidades escogidas son corredores de vida silvestre y permiten hacer un muestreo representativo de fauna, además el acceso es relativamente fácil para la recopilación de datos. Hasta la fecha, hemos identificado 11 especies de mamíferos, incluyendo gato montés (*Lynx rufus*), cacomixtle (*Bassariscus astutus*) y cholugo (*Nasua narica*).

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Biogeography and diversity of pines in the Madrean Archipelago. Pines are important dominants in pine-oak (POF) and mixed-conifer forest (MCF) in the Sierra Madre Occidental (SMO) and in the Sky Islands in the United States and México. Of the 15 native species of pines that occur in this region, most (11) have affinities to Madrean biotic communities of the SMO in México; four have affinities with Great Basin and Rocky Mountains biotic communities in the United States. In general the diversity and density of pines increase with the area and elevation range of mountain ranges. Lower and smaller ranges have 0-4 species; higher ranges (>1 km² above 2300 m elevation) have 4-7 species. With 11 species in the Municipio de Yécora eastern Sonora, the diversity of pines in the SMO is higher than any Sky Island. *Pinus arizonica* and *P. engelmannii* are common in POF, while *P. strobiformis* is typical of MCF. Several species of pines reach the margins of their geographic ranges in the region, such as *Pinus ponderosa* var. *scopulorum* in the Sierra San José near the Arizona border, and *P. cembroides* and *P. lumholtzii* in the Yécora area; *P. yecorensis* in the Sierras de Bacadéhuachi and Huachinera are range extensions from the SMO. The Eurasian *Pinus sylvestris* is locally introduced in the Sierra de los Ajos.

Biogeografía y diversidad de pinos en el Archipiélago Madreño. Los pinos son importantes especies dominantes en bosques de pino-encino (BPE) y bosques de coníferas mixtas (BCM) en la Sierra Madre Occidental (SMO) y en las Islas Serranas de Estados Unidos y México. De las 15 especies de pinos nativos que ocurren en esta región, la mayoría (11) tiene afinidades con las comunidades bióticas Madreñas de la SMO en México; cuatro tienen afinidades con las comunidades bióticas de la Gran Cuenca y las Montañas Rocallosas de Estados Unidos. En general la diversidad y densidad de pinos aumenta con el área y el rango de elevación de las cadenas montañosas. Las sierras más bajas y más pequeñas tienen de 0 a 4 especies; las sierras más altas (>1 km² arriba de los 2300 m de elevación) tienen de 4 a 7 especies. Las 11 especies en el municipio de Yécora en el este de Sonora, demuestran que la diversidad de pinos en la SMO es más alta que en cualquier Isla Serrana. *Pinus arizonica* y *P. engelmannii* son comunes en BPE, mientras que *P. strobiformis* es típico de BCM. Varias especies de pinos alcanzan los límites de sus rangos geográficos en la región, como son *Pinus ponderosa* var. *scopulorum* en la Sierra San José cerca de la frontera con Arizona, y *P. cembroides* y *P. lumholtzii* en el área de Yécora; los *P. yecorensis* en las Sierras de Bacadéhuachi y Huachinera son una extensión desde la SMO. El pino euroasiático *Pinus sylvestris* está introducido de forma local en la Sierra de los Ajos.

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Building capacity in Mexico through workshops on research, conservation and monitoring Methods for bats and amphibians in Sonora, Mexico. There is an ongoing need to train and support managers and biologists in Sonora to facilitate conservation, monitoring, and management of the many listed and sensitive species that occur on both sides of the international border. Beginning in 2008, Naturalia, a Sonora-based non-governmental organization, the U.S. Fish and Wildlife Service, Arizona Game and Fish Department, Bat Conservation International, and The

Phoenix Zoo conducted workshops on bat and amphibian monitoring and conservation at reserves in Sonora managed by Naturalia. Workshops were regionally specific to encourage local conservation efforts, and were free of charge to participants. Through lectures, demonstrations, and field exercises conducted in Spanish, workshop participants learned about species identification, study techniques, study design, survey and monitoring methods, habitat assessment and management, threats to amphibians and bats, and conservation planning. Workshops have been extremely well received and there is continued interest for future workshops. Over time, the primary responsibilities of identifying and implementing monitoring, protection and conservation activities and holding training workshops for new participants will be shifted to partners that have previously been trained in our efforts. We will present the evolution of this program and discuss opportunities for future partners in this program.

Fortalecimiento de capacidades en México con talleres de métodos de investigación, conservación y monitoreo de murciélagos y anfibios en Sonora, México. Existe una necesidad continua de entrenamiento y apoyo a personal de áreas protegidas y biólogos de Sonora para facilitar la conservación, monitoreo y manejo de las varias especies sensitivas y con categoría de riesgo que ocurren en ambos lados de la frontera internacional. Desde 2008 Naturalia (ONG en Sonora), el U.S. Fish and Wildlife Service, el Arizona Game and Fish Department, Bat Conservation International, y The Phoenix Zoo realizaron talleres sobre monitoreo y conservación de murciélagos y anfibios en reservas de Sonora a cargo de Naturalia. Los talleres se centraron en la región para fomentar esfuerzos de conservación local y se ofrecieron de forma gratuita. Por medio de clases, demostraciones y prácticas de campo en español, los participantes aprendieron como identificar especies, desarrollar un estudio, técnicas de investigación, métodos de monitoreo y censo, evaluación del hábitat y manejo, amenazas para anfibios y murciélagos, y como elaborar un plan de conservación. Los talleres recibieron muy buena aceptación y hay un interés continuo por más. Con el tiempo, la responsabilidad de identificar y desarrollar las actividades de monitoreo, protección y conservación, así como organizar talleres de capacitación para nuevos participantes se pasará a los colaboradores entrenados previamente. Se presentará la evolución de estos talleres y se analizarán oportunidades para socios futuros de este programa.

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Soil erosion and deposition before and after fire in oak savannas of the Southwestern Borderlands. Soil erosion and deposition before and after prescribed burning treatments and a wildfire on the hillslopes of the Cascabel Watersheds in the oak savannas of the Southwestern Borderlands is the focus of this paper. Measurements of soil erosion and deposition were analyzed separately because they represented separate processes of soil movements on the watersheds. The measurements were obtained in the spring and fall to characterize the soil movements following winter and summer rainstorms, respectively. Parenthetically, all of the burning events on the watersheds were low severity fires. Relationships between seasonal soil erosion and deposition following the burning events and the rainfall after these events, physiographic characteristics of the hillslopes, and post-burn vegetation on the watersheds were analyzed for possible cause-and-effect implications. The information presented should be useful to managers in developing strategies for the introduction of more natural fire regimes into the oak savannas of the region.

Erosión y deposición de suelo antes y después de incendios en pastizales con encino en la zona fronteriza del Suroeste Norteamericano. El objetivo de esta investigación es la erosión y deposición de suelos antes y después de quemas prescritas y de un incendio natural en los cerros de la cuenca Cascabel en el ecosistema pastizal con encino de la zona fronteriza del Suroeste. Se hicieron análisis por separado de las medidas de erosión y deposición ya que representan procesos diferentes de movimiento de suelo en la cuenca. Las medidas se tomaron durante la primavera y el otoño para caracterizar el movimiento del suelo después de las lluvias de invierno y de verano respectivamente. A modo de aclaración, todos fueron incendios de baja intensidad. Interacciones entre erosión y deposición estacional después de las quemas y la precipitación, características fisiográficas de los cerros, y vegetación posterior al fuego fueron analizadas para entender implicaciones causa y efecto. Esta información puede servir para desarrollar estrategias para introducir regímenes más naturales de fuego en el ecosistema pastizal con encino.

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Patterns and drivers of bird species distribution in the Madrean Sky Islands of Sonora, México. The distribution and status of breeding birds in the Madrean Sky Islands of Sonora, México have not been described since the 1950s. Moreover, the effects of local habitat suitability, habitat area, movement behavior, and interspecific interactions in driving distribution patterns in the region are unknown. To assess the patterns and drivers of bird distribution and provide information for conservation planning and management, we began a project in spring 2009 that will continue through summer 2012. During the past three field seasons, we surveyed birds and quantified environmental conditions at over 800 points along 115 transects between 1,170 and 2,600 m elevation in 17 Sky Islands in Sonora. Thus far, we have observed 122 species of birds that at least presumably breed (48% confirmed breeding) in Madrean environments in the study area including eight species that had not been observed previously in the region, and an additional six species that possibly breed yet evidence was insufficient to presume so. We will describe some notable observations while presenting our investigative framework to assess the drivers of distribution across a range of species that vary in their habitat use, movement behavior, and biogeographic affinity.

Patrones y factores de distribución de aves en las Islas Serranas Madrenses de Sonora, México. La distribución y el estatus de aves que se reproducen en las Islas Serranas Madrenses de Sonora, México no se ha descrito desde la década de 1950. Por otra parte, se desconocen los efectos de la condición y área del hábitat local, el comportamiento de movimiento y las interacciones entre especies que impulsan los patrones de distribución en la región. En la primavera de 2009 para terminar el verano de 2012 se empezó un proyecto con el fin de evaluar los patrones y factores principales de distribución de pájaros y generar información para la planeación de su conservación y manejo. En las tres temporadas de trabajo de campo previas se censaron aves y se cuantificaron las condiciones ambientales en más de 800 puntos en 115 transectos entre los 1,170 y 2,600 m de elevación en 17 Islas Serranas de Sonora. Hasta ahora se han observado 122 especies de pájaros que se piensa que se reproducen (48% reproducción confirmada) en ambientes Madrenses en el área de estudio, entre ellas ocho especies que no se habían observado anteriormente en la región y otras seis especies que posiblemente se reproducen pero aún no se ha confirmado. Se presentará la estrategia de investigación para evaluar los factores de distribución de varias especies con diferente uso del hábitat, comportamiento de movimiento y afinidad biogeográfica, también se describirán observaciones notables.

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Ephemeral streams and hydriparian vegetation in Pima County, Arizona. We compared the distribution of riparian vegetation relative to water resource availability across diverse elevational gradients for a 2.3 million-acre region for the Sonoran Desert Conservation Plan (SDCP). We analyzed the distribution of riparian vegetation along the watercourses by intersecting watercourse centerlines with vegetation polygons. Miles of stream length was summed for ephemeral, intermittent and perennial reaches identified in the SDCP inventory per five hydriparian categories of riparian vegetation. Most of Pima County's hydriparian vegetation occurs along stream reaches that classify as ephemeral. Ninety percent or more of the mesquite woodlands, riparian scrub and riparian strand classifications of the Brown, Lowe, and Pase system are associated with ephemeral stream reaches in Pima County. Over half of the Sonoran cottonwood-willow vegetation is associated with stream reaches that classified as ephemeral. Conservation planning has often focused on protecting perennial stream habitat. Our results support the importance of identifying and protecting ephemeral and intermittent streams, particularly those having shallow groundwater tables. The SDCP includes a number of provisions to protect or conserve non-perennial stream environments, including refined floodplain management regulations, new land and water infrastructure review guidelines, and land acquisition.

Arroyos efímeros y vegetación riparia en el Condado de Pima, Arizona. Se comparó la distribución de la vegetación riparia dependiendo de los recursos hídricos disponibles en un gradiente altitudinal para una región de 930 776 ha. dentro del Plan de Conservación del Desierto Sonorense (SDCP, Sonoran Desert Conservation Plan). Se analizó la distribución de la vegetación riparia a lo largo de lechos de arroyos por medio de transectos usando el cruce de las líneas centrales con polígonos de vegetación. Se realizaron largos recorridos en zonas efímeras, intermitentes o perennes tal como lo indica el inventario SDCP para cinco categorías de vegetación riparia. La mayoría de la vegetación riparia del Condado de Pima se desarrolla a lo largo de arroyos clasificados como efímeros. Noventa por ciento o más de mezquite, matorral ripario y ramal de las clasificaciones de Brown, Lowe y Pase están asociados con sistemas efímeros. Mas de la mitad de la vegetación sonorense de álamo y sauce está asociada a zonas efímeras. La planeación para la conservación se ha enfocado en arroyos perennes. Nuestros resultados apoyan la importancia de identificar y proteger arroyos efímeros e intermitentes, especialmente aquellos con acuíferos someros. La SDCP incluye un gran número de disposiciones para proteger y conservar zonas ambientales de arroyos no perennes, incluyendo zonas de inundación, adquisición de tierras e infraestructura y revisión de lineamientos.

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Restoration at Bingham Ciénega, Pima County, Arizona. Bingham Ciénega is located on a 285-acre preserve just north of the town of Redington in the San Pedro River valley. It is owned by the Pima County Regional Flood Control District (District) and managed by The Nature Conservancy (TNC). During the last century, about 50 acres of the site, including much of the ciénega, were grazed and farmed. Long-time residents report that the spring and its ciénega has varied considerably in discharge and extent over time, and in 1957, most of the ciénega was drained and cultivated. After acquiring the site, we began a program of study and analysis, while allowing passive restoration via drainage ditch abandonment. After 1989, the ciénega expanded in size and became increasingly vegetated with bulrush, cattail, ash, buttonbush and willow. In 1998, an active restoration began, based upon depth-to-water planting zones within the fields, and historical vegetation research. Three planting zones were identified; deciduous riparian woodland, sacaton grassland, and mesquite woodland, each zone marked by progressively deepening water levels. Three years later, the Nature Conservancy revegetated 25 acres of farmland using Arizona Water Protection and Flood Control District funding. Since 1998, water levels have deepened. Spring flow completely ceased in 2003 and has only briefly resumed. The naturally restored bulrush marsh to the point is now dominated by annuals, though some willow and buttonbush remain. The actively restored sacaton has been reduced in some area, with the best cover in the year 1 field. A mix of mesquite and sacaton, similar to the natural condition of the former ciénega outflow, may be the long-term outcome for the ciénega margins. Fire management has been and remains an important focus of effort.

Restauración de la Ciénega Bingham, Pima County, Arizona. La Ciénega Bingham se localiza en una reserva de 115 ha justo al norte de Redington en el valle del río San Pedro. Pertenece al Distrito de Control de Inundaciones del Condado Pima (Distrito) y la administra la Conservación de la Naturaleza (Nature Conservancy, TNC). Durante el siglo pasado, aproximadamente 20 ha, incluyendo la ciénega, fueron utilizadas para ganadería y agricultura. Residentes de antaño reportan que el manantial y la ciénega han variado considerablemente en descarga y extensión, en 1957, casi toda la ciénega fue drenada y cultivada. Después de adquirir el sitio comenzamos una serie de estudios y análisis,

permitiendo la restauración pasiva vía abandono de la zanja de drenaje. Después de 1989, la ciénega se expandió y la cubierta vegetal se vio enriquecida con juncos (*Scirpus* sp.), tule (*Typha domingensis*), fresno (*Fraxinus velutina*), mimbro (*Cephalanthus* sp.), y sauce (*Salix* sp.). El proceso de restauración activa comenzó en 1998, se establecieron zonas de plantación basadas en la profundidad del agua y se investigó la vegetación histórica. Se identificaron tres zonas para plantación; bosque ribereño caducifolio, pastizal de zacatón, y mezquital; cada zona identificada conforme aumenta la profundidad del agua. Tres años después, Conservación de la Naturaleza reforestó 10 ha con fondos del Distrito El nivel del agua ha ido bajando desde 1998. El flujo del manantial cesó por completo en el 2003. La zona restaurada de forma natural con juncos está dominada por anuales con pocos sauces y mimbros. El zacatón se ha visto reducido en algunas zonas. Una mezcla de mezquite y zacatón, similar a la de las condiciones naturales de la ciénega, puede ser el resultado a largo plazo. El manejo de incendios fue y sigue siendo un proceso importante de éstos trabajos.

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Diversity and species composition of ant assemblages in the Santa Catalina Mountains. Ants are a dominant faunal group in nearly all terrestrial ecosystems and play important roles in numerous ecosystem processes. In North America, ant diversity peaks in the desert Southwest, and exceptionally high levels of diversity can be found in the Sky Island region. For example, over 180 species have been documented in the Chiricahua Mountains of southeastern Arizona. Despite exceptional levels of diversity and great functional importance, ant assemblages of the sky islands remain poorly studied. We have developed a long-term sampling protocol designed to document and monitor ground-dwelling arthropod communities in the Santa Catalina Mountains. The design consists of 100 meter transects with 10 pitfall traps deployed at each of 66 sites that span the elevational gradient. Preliminary analysis of the ant data indicates that the diversity of ant assemblages decreases with elevation, and species turnover across the elevational gradient is high. Transitions between ant assemblages across elevation appear to occur in congruence with transitions among plant biomes. Understanding which factors structure ant assemblages across elevation gradients in the sky islands will be essential to predicting the impact of climate change on ant diversity and on the ecosystem services they provide.

Diversidad y composición de especies de los ensambles de hormigas en la Sierra Santa Catalina. Las hormigas son un grupo de fauna dominante en casi todos los ecosistemas terrestres y desempeñan un papel importante en numerosos procesos del ecosistema. En América del Norte, la diversidad de hormigas alcanza su máxima diversidad en el Suroeste árido de Estados Unidos y niveles de diversidad bastante altos se encuentran en la región de las Islas Serranas. Por ejemplo, más de 180 especies se han registrado en la Sierra Chiricahua del sureste de Arizona. A pesar de los altos niveles de diversidad y su gran importancia funcional, los ensambles de hormigas de las islas serranas aún son muy poco estudiados. Hemos desarrollado un protocolo de muestreo a largo plazo diseñado para documentar y monitorear las comunidades de artrópodos que viven en la tierra en la Sierra Santa Catalina. El diseño consiste de transectos de 100 metros con 10 trampas de caída en cada uno de los 66 sitios de muestreo que abarca el gradiente de elevación. Los análisis preliminares de datos indican que la diversidad de los ensambles de hormigas disminuye con la elevación y que el movimiento de especies es alto en el gradiente de elevación. Las transiciones entre los ensambles de hormigas en los diferentes rangos de elevación parecen ocurrir en relación con las transiciones entre los biomas vegetales. El entender cuales factores influyen los ensambles de hormigas en los gradientes de elevación de las islas serranas será fundamental para predecir el impacto del cambio climático en la diversidad de hormigas y los servicios ecosistémicos que proporcionan.

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Reestablishment and protection of a Chiricahua Leopard Frog population in Scotia Canyon, Huachuca Mountains, Arizona. Bullfrogs are significant impediments to recovery of native aquatic amphibians and reptiles in riparian systems in the American Southwest. Until recently, bullfrog control across a landscape with many stock ponds was considered unlikely to succeed. In 2008, however, the Coronado National Forest launched a multi-year, multi-partner project to eliminate bullfrogs within a 113 km² area centered on Scotia Canyon in the Huachuca Mountains. We eliminated all bullfrogs in Scotia Canyon and reestablished Chiricahua leopard frogs. Bullfrogs were removed at 10 stockponds and along 3.7 km of stream within 6 miles of Scotia Canyon. We focused control efforts at perennial ponds and 130-acre Parker Canyon Lake. We found adult bullfrogs in the Cave Canyon watershed during the summer monsoon season traveling to headwaters with direct connections to Scotia Canyon. Bullfrogs reinvaded some stock ponds but not Scotia Canyon, where leopard frogs have continued to persist. The Forest Service in cooperation with the livestock grazing permittee has developed plans to manage stock ponds to disrupt bullfrog dispersal and control their reproduction. How to simultaneously maintain multiple stock ponds for livestock and native wildlife without perpetuating invasive species is a management challenge that is likely to increase in complexity with climate change.

Reintroducción y protección de la población de la rana de Chiricahua en Scotia Canyon, Sierra Huachuca, Arizona. Las ranas toro impiden de manera significativa la recuperación de anfibios y reptiles en los sistemas ribereños del Suroeste Norteamericano. Hasta hace poco el control de ranas toro en una región con muchos represas de abrevadero se consideraba imposible. Sin embargo en el 2008, el Bosque Nacional Coronado empezó un proyecto de varios años junto con otras instituciones, para eliminar las ranas toro en 113 km² en Scotia Canyon de la cordillera Huachuca. Se eliminaron todas las ranas toro de Scotia Canyon y se reintrodujo la rana de Chiricahua. Se eliminaron las ranas toro de 10 represas y de un tramo de 3.7 km de un arroyo cerca de 10 km de Scotia Canyon. Los trabajos de control se enfocaron en estanques

permanentes y 53 has de Parker Canyon Lake. Se encontraron ranas toro adultas en la subcuenca Cave Canyon durante la estación del monzón de verano, trasladándose al nacimiento de arroyos con conexiones directas a Scotia Canyon. Las ranas toro reinviadieron algunos repesos pero no Scotia Canyon, donde la rana de Chiricahua aún persiste. El Servicio Forestal a través de su programa de permisos para el pastoreo de ganado ha desarrollado un programa para manejar los repesos para bloquear la dispersión y reproducción de la rana toro. Es un gran reto mantener simultáneamente múltiples repesos para el ganado y fauna silvestre sin perpetuar especies invasoras y este problema probablemente aumentará bajo las influencias del cambio climático.

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Transborder Climate and experiments in climate communication: Building a foundation for adaptation. In recent years, U.S.-Mexico border region stakeholders have consistently articulated needs for climate services to provide information, enhance preparedness, and better inform resource management decisions. We report on a NOAA-funded initiative in the Madrean Archipelago region to not only provide information, but to build capacity for adaptation. The initiative augments the Border Climate Summary/Resumen del Clima de la Frontera PDF newsletter, through experiments in climate communication. We focus on *Transborder Climate*, a brief bulletin that gives a high-level overview of climate forecasts and research. We also report on experiments in the use of bilingual webinars and social media to increase knowledge exchange and build a foundation for adaptation to climate change. These experiments are being conducted by a consortium of collaborators from University of Arizona, UNISON, CIBNOR, CICESE, and the Southern Regional Climate Center. We report on the early stages of these experiments and the methods and metrics for evaluating the use of these media and their value to border region decision makers.

Clima transfronterizo y programas piloto de comunicación sobre clima: estableciendo bases para la adaptación. Los últimos años, los sectores interesados de la región fronteriza entre México y E.U. han expresado la necesidad de que el servicio climatológico proporcione mayor información, medidas de seguridad y fuentes de información útiles en los programas de manejo. Presentamos el proyecto NOAA de la región del Archipiélago Madreño, que además de informar explora estrategias de adaptación. El proyecto enriquece el boletín en línea “Resumen del clima de la frontera / Border Climate Summary”, con programas sobre comunicación del clima. Presentamos *Clima Transfronterizo*, un boletín con reseñas de investigación y pronóstico de clima. También introducimos el uso de cursos y seminarios bilingües en línea y redes sociales para facilitar el intercambio de ideas y establecer bases de adaptación al cambio climático. Estos programas piloto se llevan a cabo gracias a la colaboración de University of Arizona, UNISON, CIBNOR, CICESE y Southern Regional Climate Center. Se presenta el inicio de estos programas, la metodología y medidas de evaluación del uso de medios electrónicos y su importancia para los directivos de la región fronteriza.

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FireScape: A program for whole-mountain fire management in the Sky Island Region. Poster. The Coronado National Forest’s (CNF) FireScape program works to remove barriers to fire playing its natural role on the landscape. A long-term goal is creating landscapes that are able to survive wildfire with biodiversity intact, especially important in the face of a drier, hotter Southwest. The FireScape team is nurturing multiple efforts around the Sky Islands—no two projects are alike, but those underway share an approach that includes multiple jurisdictions, investigations by University of Arizona scientists, public engagement, assessing treatment need at the whole-mountain scale, and creatively removing implementation barriers when funding is scarce. Clearance for treatments in designated Wilderness is a need across all projects. The FireScape team has completed a fuels map and an analysis of departure from reference condition for southeastern Arizona that covers the CNF and partner lands. Partners have worked together to update Landfire data for this 14 million-acre area. These products provide inputs for fire behavior and effects analyses to support decision-making and outreach. The website www.azfirescape.org is a work in progress that displays project information, including maps, reports, and vegetation and fuels data.

FireScape: Un programa para el manejo integral de incendios en las Islas Serranas. El programa FireScape del Coronado National Forest (CNF, Bosque Nacional Coronado) trabaja para quitar barreras que impiden al fuego desempeñar su papel natural en el paisaje. La meta a largo plazo es crear paisajes capaces de sobrevivir incendios naturales sin afectar la biodiversidad, especialmente ante un escenario seco y más caliente en el Suroeste Norteamericano. El personal de FireScape está desarrollando varios trabajos en las Islas Serranas, ninguno de los proyectos es similar, pero los que están en marcha se semejan al incluir varias jurisdicciones, investigaciones científicas de la University of Arizona, participación de la ciudadanía, evaluación de tratamientos en toda la montaña, y creatividad para remover las barreras con presupuesto escaso. En áreas naturales protegidas se necesita autorización en cualquier proyecto. El personal de FireScape elaboró mapas de áreas propensas a incendios y análisis de puntos de ignición de referencia para el sureste de Arizona, que cubre el CNF y zonas cercanas. Los socios colaboraron para actualizar la información de estos 5.7 millones de ha. Estos mapas y reportes aportan información sobre el comportamiento del fuego y análisis que sirven en las decisiones de manejo e información a la ciudadanía. La página electrónica www.azfirescape.org se actualiza constantemente para presentar información de proyectos, mapas, reportes y datos de vegetación y combustible.

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Hillslope treatment effectiveness monitoring on Horseshoe 2 and Monument Fires. In 2011, the Coronado National Forest experienced one of the most active fire seasons in recorded history when fires burned over 360,000 acres between February and July. Burned Area Emergency Response (BAER) Teams evaluated post-fire watershed conditions and prescribed treatments based on threats to known values at risk. Hillslope stabilization treatments were prescribed and implemented for areas of high soil burn severity on both Horseshoe 2 and Monument Fires. These treatments consisted of seeding on the Horseshoe 2 Fire and application of agricultural straw mulch and seed on the Monument Fire. Based on initial monitoring results one of three seeded species (*Hordeum vulgare*) emerged in both burned areas, slightly improving effective ground cover in both treatments. However, seeding treatments failed to meet monitoring success criteria for both fires. Hillslope erosion was reduced where mulch treatment was applied correctly and where slopes were gentle on the Monument Fire, and appeared to contribute to seeded species cover. In the Horseshoe 2 Fire hillslope erosion was high in the treatment units and was not sufficiently reduced by seeding alone. A need for additional monitoring in spring 2012 exists and would improve the current understanding of the effectiveness of hillslope treatments.

Monitoreo de la eficacia de tratamiento en laderas de los incendios Horseshoe 2 y Monument. El Coronado National Forest experimentó en el 2011 una de las temporadas más activas de incendios forestales en la historia, más de 145,686 ha fueron afectadas entre febrero y julio. Las brigadas de BAER (siglas en inglés de brigadas de emergencia para incendios) evaluaron la situación posterior al fuego en la cuenca y prescribieron tratamientos basados en amenazas a recursos en riesgo. Los tratamientos para la estabilización de laderas fueron recomendados e implementados en área donde se detectó suelo con incendios severos en *Horseshoe 2* y *Monument*. En *Horseshoe 2* el tratamiento que se aplicó fue siembra mientras que en *Monument* se aplicó un mantillo de paja y siembra. Los monitores preliminares demuestran que una de las tres especies sembradas (*Hordeum vulgare*) germinó en las dos zonas afectadas, mejorando ligeramente la cobertura vegetal en ambos tratamientos. Sin embargo, el tratamiento de siembra no cumple con las expectativas de éxito en ninguno de los sitios. La erosión en laderas disminuyó cuando el tratamiento de mantillos se aplicó correctamente y con pendientes ligeras en el incendio *Monument*, esto contribuyó a la cobertura vegetal de especies sembradas. En *Horseshoe 2* la erosión fue mayor en las áreas tratadas y el sembrado sin mantillo no la disminuyó. Se requieren más monitoreos en la primavera de 2012 para mejorar nuestro entendimiento de la eficacia de tratamiento de laderas.

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Livestock depredation occurrence by mountain lions (*Puma concolor*) in the Sierra San Luis, Sonora. The ability to predict the occurrence of wildlife-livestock conflicts would benefit both the livestock producers and the predators that prey upon them. Little has been done to reduce this conflict using modeling tools. As such, our aim for this study was to create a depredation risk model for livestock in the Sierra San Luis, Sonora. We modeled the probability of occurrence of pumas and livestock using program PRESENCE. Covariates involved in the model include elevation, slope, aspect, NDVI. Point locations for pumas and livestock were obtained using camera trap surveys obtained between 2009 and 2011. Using ArcGIS we combined the occurrence of pumas and livestock and developed a low to high probability of depredation where areas of overlap occur. We considered the highest probability of depredation to occur at piedmont, rugged areas, and closed cover. The results from this study can be used to improve livestock management and to recommend livestock rotation in the area.

Depredación de ganado por pumas (*Puma concolor*) en la Sierra San Luis Sonora. La habilidad de predecir conflictos entre fauna silvestre y ganado puede ser útil tanto a los productores de ganado como a los predadores. Se ha hecho muy poco para resolver este conflicto empleando modelos computarizados. El objetivo de este estudio fue generar un modelo de riesgo de depredación en la Sierra San Luis, Sonora. Modelamos la probabilidad de encuentros entre pumas y ganado empleando el programa PRESENCE. Las covarianzas usadas en el modelo son elevación, pendiente, aspecto, NDVI. Localidades puntuales para pumas y ganado se obtuvieron empleando cámaras trampa entre 2009 y 2011. Empleando ArcGis combinamos la presencia de pumas y ganado y desarrollamos la probabilidad de depredación de menor a mayor en las áreas donde coexisten. Consideramos que la mayor probabilidad de depredación existe en el piedemonte, zonas escarpadas y de cobertura cerrada. Los resultados pueden ser empleados para mejorar el manejo de ganado y recomendar la rotación del ganado en el área.

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Ecosystems and diversity of the Sierra Madre Occidental. The ecosystems and vegetation of the Sierra Madre Occidental (SMO) were mapped using ArcView, based on Landsat images and field verification. Data on the composition, distribution and ecological determinism of the vegetation are presented. The Sierra Madre Occidental is the biggest continuous ignimbrite plate on Earth. With a complex geological history and a high biological and cultural diversity, it is a biological corridor, a barrier for the surrounding elements and an active center of speciation, yet ecologically not well known. We describe the vegetation of the SMO above 1,800 m asl. Ecosystems are described along a gradient from tropical deciduous forests to high montane communities. The most widespread communities are the Madrean pine-oak forests and woodlands. Among the dramatic changes occurring—besides fragmentation and deforestation driven by humans—are the effects of bark beetle (*Dendroctonus*) infestations that have killed extensive areas of pines (and also affected fir, Douglas fir and spruce), which were likely already stressed by drought. Other changes included the expansion of chaparral driven by disturbance and the dwindling of oak woodlands, which are being replaced by *Dodonaea viscosa*, an invader from warmer areas.

Diversidad y ecosistemas de la Sierra Madre Occidental. Los ecosistemas y la vegetación de la Sierra Madre Occidental (SMO) fueron cartografiados usando ArcView, con base en imágenes Landsat y verificación de campo. Se presentan datos sobre la composición, distribución y determinismo ecológico de su vegetación. La Sierra Madre Occidental es la placa continua de ignimbrita más grande sobre la Tierra. Con una compleja historia geológica y una gran diversidad biológica y cultural, la SMO es un corredor biológico, una barrera para los elementos que la rodean y un centro activo de especiación; sin embargo, biológica y ecológicamente todavía no se conoce bien. En este trabajo se describe la vegetación de la SMO por encima de los 1,800 m snm a lo largo de un gradiente desde los bosques tropicales deciduos hasta las comunidades de alta montaña. Las comunidades más ampliamente distribuidas son los bosques madrenses de pino-encino y los bosques bajos abiertos. Entre los dramáticos cambios que están ocurriendo—además de la fragmentación y la deforestación antropogénicas—están los efectos de las infestaciones por descortezadores (*Dendroctonus*) que han destruido extensas áreas de pinares (y afectado también a *Abies*, *Pseudotsuga* y *Picea*), previamente estresados y debilitados por sequía. Otros cambios incluyen la expansión de chaparrales favorecidos por disturbio y la reducción de encinares, los cuales están siendo reemplazados por *Dodonaea viscosa*, un arbusto invasor proveniente de áreas más cálidas.

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Ecology and management of oak woodlands and savannas in the southwestern borderlands region. Management of the Madrean oak woodlands and the less dense and ecologically different oak savannas has become more complicated in recent years and, therefore, must be based on sound ecological information. However, relatively little is known about the Madrean oak ecosystems in spite of the fact that they cover about 80,000 km² in the southwestern United States and northern Mexico. Emory oak (*Quercus emoryi*) is the dominant tree in most stands and is usually associated with other oak species and juniper. Trees are utilized for firewood, fence posts, and construction materials and acorns are gathered as food by local inhabitants. The woodlands and savannas are important for wildlife habitat, including habitats for listed and sensitive species, watershed protection, and livestock grazing. Tree regeneration and water consumption are important considerations. Tree harvesting has been restricted because of heavy utilization in the past but coppice management could ease the supply situation. Recreational demands and fire management concerns are increasing as populations grow in southern Arizona. This presentation reviews the ecology and management of oak woodlands and savannas based on recent research findings along the border and relevant literature from the United States and northern Mexico.

Ecología y manejo de encinales y pastizales en la zona fronteriza del Suroeste Norteamericano. En el Archipiélago Madrense el manejo del encinal y del pastizal con encino, menos denso y con ecología diferente, se ha complicado en los últimos años, por lo tanto debe basarse en información ecológica sólida. Sin embargo existe muy poca información de estos ecosistemas a pesar de que cubren 80,000 km² del suroeste de Estados Unidos y noroeste de México. La bellota (*Quercus emoryi*) por lo general es el árbol dominante del arbolado y comúnmente asociado con otras especies de encino y táscale. Los árboles son utilizados como leña, postes y materiales de construcción, y el fruto es colectado para alimento por lugareños. El encinal y el pastizal son importantes hábitat para animales, incluyendo especies sensibles y en peligro, protección de la cuenca y pastoreo. La regeneración de árboles y consumo de agua son factores importantes. La extracción de madera se ha prohibido debido a la explotación que se dio en el pasado, sin embargo los planes de manejo pudieran ayudar en esta situación. Las demandas por zonas recreativas y el manejo de fuego son problemas cada vez mayores debido al aumento de la población en el sureste de Arizona. Esta presentación revisa la ecología y manejo de ecosistemas de encino basados en estudios en zonas fronterizas y literatura de Estados Unidos y norte de México.

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Effects of prescribed fire and wildfire on biological resources of oak savannas in the Peloncillo Mountains, New Mexico. Private and public land managers are attempting to reintroduce fire into the ecosystems of the Peloncillo Mountains in order to reduce the density of woody species, increase the herbaceous plant cover, and improve the area's ecological diversity. The Cascabel Watershed Study, which includes 12 small, gauged watersheds, was started in 2000 to evaluate the impacts of cool-season (November-April) and warm-season (May-October) prescribed fires on a number of physical and biological components of the oak (*Quercus* spp.) savannas that are common to the Southwestern Borderlands Region. A wildfire in 2008 modified the original experimental design. All three fire treatments resulted in low severity burns. The effects of the different fire treatments on tree overstories, herbaceous production, ground cover, selected wildlife species and on bird populations are presented. In general, measurements did not indicate many significant differences among treatments or with pre-fire conditions. Almost 78 percent of the overstory trees on the 12 watersheds, for example, survived the fires. The main exception was a large increase in grass and total herbaceous plant production of early-growing species after the fires. The fires also produced statistically significant increases in the production of late-growing grass species but the changes were not as large.

Efectos de quemas prescritas e incendios naturales en los recursos biológicos del pastizal de encino en las montañas Peloncillo, Nuevo México. Personal de manejo de recursos de áreas naturales del gobierno y privadas de las montañas Peloncillo están intentando reintroducir el fuego en el ecosistema con la finalidad de reducir la densidad de especies leñosas, incrementar la cobertura vegetal herbácea y mejorar la diversidad biológica del área. El estudio de la Cuenca Cascabel, que incluye 12 subcuencas con calibradores, se comenzó en el 2000 para evaluar el impacto de quemas prescritas en las estaciones frías (noviembre-abril) y cálidas (mayo-octubre) sobre componentes físicos y biológicos del

pastizal con encino (*Quercus* spp.) común en la zona fronteriza del Suroeste Norteamericano. En el 2008 un incendio natural modificó el diseño experimental inicial. Las tres quemas prescritas fueron de baja intensidad. Se presenta el efecto de los tratamientos con fuego sobre el dosel arbóreo, producción herbácea, cubierta vegetal, especies selectas de fauna y poblaciones de aves. En general los datos no muestran diferencias significativas entre tratamientos o condiciones previas al incendio. Casi el 78% del dosel arbóreo en las 12 subcuencas sobrevivieron las quemas. La excepción fue un gran aumento de zacates y producción total de herbáceas de especies tempranas después de los incendios. Los incendios también causaron aumentos estadísticos significativas de zacates de crecimiento tardío, sin embargo los cambios no fueron tan grandes.

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Effects of buffelgrass on habitat use of Sonoran Desert tortoises. Buffelgrass (*Pennisetum ciliare*) is a nonnative grass that is increasing markedly in distribution throughout the southwestern United States and Mexico. By altering ecosystem structure and function, buffelgrass has the potential to alter the quantity and quality of habitat for animals such as the Sonoran desert tortoise (*Gopherus agassizii*), which inhabits areas being invaded by buffelgrass. We examined effects of buffelgrass on habitat use of desert tortoises by surveying tortoises on 50 4-ha plots that we established across the gradient of buffelgrass cover in Saguaro National Park in 2010 and 2011. On each plot, we contrasted characteristics of vegetation and substrate in 5-m-radius plot centered on 186 tortoises with areas thought available to tortoises as measured along a systematic array of transects established across each plot. Our results will help biologists understand the threat that buffelgrass poses to this rare vertebrate in the southwestern United States.

Efectos del zacate buffel en el hábitat de la tortuga del desierto Sonorense. El zacate buffel (*Pennisetum ciliare*) es un pasto introducido que está notablemente aumentando su distribución en el suroeste de Estados Unidos y noroeste de México. El zacate buffel tiene el potencial de alterar la cantidad y calidad del hábitat cambiando la estructura y función del ecosistema, afectando a especies como la tortuga del desierto Sonorense (*Gopherus agassizii*), ya que vive en zonas donde el buffel está invadiendo. Examinamos el efecto del buffel en hábitat de la tortuga del desierto mediante un muestreo en 50 cuadrantes de 4 ha en un gradiente con buffel en el Parque Nacional Saguaro durante el 2010 y 2011. En cada cuadrante comparamos características de la vegetación y el substrato en cuadrantes de 5 m de radio centrados en 186 tortugas, con áreas probables de tortugas, conforme a los datos de transectos de arreglo sistemático en cada cuadrante. Los resultados servirán para comprender la amenaza que representa el buffel a este vertebrado escaso del Suroeste Norteamericano.

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Jaguar permanency and density in the Northern Jaguar Reserve in Sonora, México, years 1999 – 2010. The Northern Jaguar Reserve was created in order to protect the northernmost population of jaguars in the continent. Camera traps have monitored the reserve for more than 10 years. This long term monitoring effort has allowed us to evaluate jaguar population turnover. We estimated the density of jaguars by year as well as their survival rate and capture probability. We identified a total of 32 jaguar individuals over 10 years of sampling through each jaguar's unique spot pattern. The maximum time spent in the area was six years by a female. The overall residence time was 4 years. The maximum number of different individuals detected per year was 8. We calculated a home range of 84.6 km² for the male jaguar with the highest number of records since 2006. The average density of jaguars on the site was variable but averaged 1.6 (\pm 1.6) individuals/100 km²/year. According to the results, the detection probability varies with time and not with the technique used for monitoring. We consider that the use of camera traps for jaguar studies, besides being a noninvasive technique, provide sufficient information for long-term monitoring. This is the first study that involves both density and permanency for a time period of 10 years for the northern jaguar population so it cannot be compared with studies in similar habitats. However, the results of permanence agree with those obtained in long-term studies in the Amazon.

Permanencia y densidad poblacional de jaguares en la Reserva del Jaguar del Norte en Sonora, durante el período de 1999 a 2010. La Reserva del Jaguar del Norte fue creada con la finalidad proteger la población más norteña de jaguares en el continente. Ha sido monitoreada con trampas cámara por mas de 10 años, incluso desde antes de su establecimiento como reserva. Este monitoreo ha permitido evaluar los cambios poblacionales de los jaguares en el área de estudio. Para evaluar estas tendencias, se estimó la densidad de jaguares por año, así como la tasa de supervivencia y la probabilidad de captura. En total se identificó a 32 individuos de jaguar a lo largo de los 10 años de muestreo por medio de su patrón de manchas único. El tiempo máximo de permanencia en el área de estudio fue de seis años para una hembra pero en general el tiempo de permanencia resultó de 4 años. El número máximo de individuos diferentes detectados por año fue de 8. Se calculó un ámbito hogareño de 84.6 km² para el jaguar macho con el mayor número de registros a partir de 2006. La densidad de jaguares varió cada año, con un promedio de 1.6 individuales/100 km²/año. La probabilidad de detección de los jaguares varía con el tiempo y no con la técnica usada para el monitoreo por lo que se considera que el estudio con trampas cámara además de ser una técnica no invasiva para el estudio de estas poblaciones proporciona información suficiente para monitoreos a largo plazo de esta especie.

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Ocelot density in Northern Jaguar Reserve and surrounding areas in Sahuaripa, Sonora, Mexico, using an open population model.

The Northern Jaguar Reserve was established as a private reserve to provide a refuge for the northernmost population of jaguars in the continent. However, the protection afforded by the reserve has been extended to other species under some category of protection, such the ocelot, who is in danger of extinction according the Mexican legislation. In this study we calculated the density of ocelots in the area bounded by the Northern Jaguar Reserve and 10 cattle ranches adjacent to it with an agreement to protect wildlife. We sampled monthly with camera traps in the study area between 2009 and 2011. We obtained 188 ocelot photographs that we could identify to individual level. With all captures, we calculated the home range of a female in 18.84 km² and 37.14 km² for a male. We calculated the density for each month of sampling and the average density was 4.11 (\pm 1.42) individuals / 100 km². The average survival probability (ϕ) was 0.71 (\pm 0.16). The use of open population models for calculating the density of a species can include births and deaths, which gives more reliable results, allowing to study strategies and conservation of the species in the long term.

Densidad de ocelotes, usando un modelo de población abierta, en la Reserva del Jaguar del Norte y zonas aledañas en Sahuaripa, Sonora, México. La Reserva del Jaguar del Norte fue establecida como reserva privada para proveer un refugio para la población más noroeste de jaguares del continente, sin embargo, la protección brindada por la Reserva se ha extendido a otras especies bajo alguna categoría de protección, como el ocelote que se encuentra en peligro de extinción en la legislación mexicana. En este estudio calculamos la densidad de ocelotes en el área comprendida por la Reserva del Jaguar del Norte y 10 ranchos ganaderos aledaños a ésta con convenio de protección a la fauna silvestre. Hicimos muestreos mensuales con trampas cámara en la zona de estudio entre 2009 y 2011. Obtuvimos 188 fotografías de ocelote identificables a nivel de individuo. Con los datos de capturas fotográficas, calculamos el ámbito hogareño de una hembra en 18.84 km² y de un macho en 37.14 km². Calculamos la densidad para cada mes de muestreo y la densidad promedio fue de 4.11 (\pm 1.42) individuos/ 100 km². La probabilidad de supervivencia (ϕ) promedio fue de 0.71 (\pm 0.16). El uso de modelos de poblaciones abiertas para el cálculo de densidad de una especie permite incluir muertes y nacimientos, lo cual da mayor confiabilidad a los resultados, y sirve para generar estrategias de estudio y conservación de la especie a largo plazo.

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Mammalian community comparisons related to cattle presence. Livestock husbandry is an activity that can affect mammal distribution and community structure. To test such effect we considered a site with and without livestock. The Northern Jaguar Reserve is a privately owned with no cattle beginning in 1999, surrounded by working cattle ranches. Using camera traps we compared mammalian abundance and dominance, both at the reserve and 10 adjacent ranches for three years. We recorded 17 species of medium and large mammals. Only peccary (*Pecari tajacu*) showed higher abundance values on cattle ranches than on the reserve. The ringtail (*Bassariscus astutus*) and the spotted skunk (*Spilogale gracilis*) had similar abundances inside and outside the reserve. The 14 remaining species showed higher abundances in the reserve, including jaguar and ocelot. The feline abundance also showed differences between sites with abundances in the reserve significantly higher than outside. These results serve as a basis for understanding the effects of livestock and ecosystem recovery after exclusion, and livestock management strategies that are compatible with the habitat recovery of mammal species

Comparación de la comunidad de mamíferos en relación con la presencia de ganado. La ganadería es una actividad que puede llegar a desplazar las poblaciones de mamíferos o alterar la estructura de la comunidad de éstos. Un modelo para estudiar este efecto necesita por lo menos dos factores, un sitio sin ganado y uno con presencia del mismo. La Reserva del Jaguar del Norte es una propiedad privada cuya exclusión de ganado ha sido gradual y está rodeada de ranchos ganaderos. Mediante trampeo fotográfico se ha monitoreado mensualmente tanto la reserva como 10 ranchos aledaños a esta por 4 años. Se hicieron comparaciones de la abundancia relativa y la dominancia de especies en ambas zonas con la finalidad de determinar si la presencia de ganado afecta la estructura de la comunidad. El estudio se llevó a cabo con 17 especies de mamíferos medianos y grandes. Del total de especies, el jabalí (*Pecari tajacu*) presentó mayor abundancia en los ranchos ganaderos. El cacomixtle (*Bassariscus astutus*) y el zorrillo manchado (*Spilogale gracilis*) tuvieron abundancias similares dentro y fuera de la reserva. El resto de las especies presentaron abundancias mayores en la reserva. Las abundancias de felinos dentro de la reserva fueron significativamente mayores que fuera de ella, estando el jaguar y ocelote poco representados en la zona con ganado. Estos resultados sirven como base para entender los efectos del ganado y la recuperación del ecosistema después de su exclusión y las estrategias de ganado que sean compatibles con la recuperación de hábitat para las especies de mamíferos.

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A review of black-tailed prairie dog reintroduction strategies and site selection. The black-tailed prairie dog was once widely distributed throughout the Western United States; however, anthropogenic influences have reduced their numbers to 2% of what they were historically. Black-tailed prairie dogs are keystone species in the grassland ecosystem, and provide many services that other species cannot, including providing burrows for other species (e.g. burrowing owls [*Athene cunicularia*] and rattlesnakes [*Crotalus sp.*]), excavating nutrient rich soil

that, in turn, provides rich vegetation for grazers, and serving as food for many carnivores and birds of prey. Several efforts have been made to reestablish this keystone species to its historical range; however, there has not been a comprehensive review outlining site selection, methodology, and success of these efforts. In southeastern Arizona, a recent reestablishment effort was built upon work of scientists that identified potential suitable areas with characteristics similar to existing prairie dog colonies in Mexico. Prairie dogs were first translocated to the sites in 2008, and individuals still remain on the landscape today. We compare this to other reestablishment efforts, and provide suggestions on ways to increase success of future reintroductions.

Análisis de las estrategias de reintroducción y selección de sitios del perrito de la pradera de cola-negra. El perrito de la pradera de cola-negra anteriormente tuvo una distribución amplia en el oeste de Estados Unidos; sin embargo actividades antropogénicas lo han reducido a 2% de la población histórica. En ecosistemas como pastizales los perritos de la pradera son especies clave y aportan innumerables servicios que otras especies no, incluyendo madrigueras para otras especies (Ej. tecolote llanero [*Athene cunicularia*] y víbora de cascabel [*Crotalus* sp.]), excavan suelo rico en nutrientes que suple con vegetación diversa a los herbívoros, y son alimento de muchos carnívoros y aves rapaces. Se han realizado grandes esfuerzos para restablecer esta especie clave a su rango histórico; sin embargo no se cuenta con una publicación detallada de la selección de sitios, metodología, y el éxito de estos trabajos. En el sureste de Arizona, una reintroducción reciente se basó en investigaciones científicas que identificaron áreas adecuadas con características similares a las colonias en México. Los perritos de la pradera se llevaron a éstos sitios en el 2008, y aún quedan individuos como parte del paisaje. Comparamos estos resultados con otros trabajos, y aportamos sugerencia para aumentar el éxito de futuras reintroducciones.

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Reduction of erosion and sedimentation along the lower San Pedro River through hydrologic restoration of modified ephemeral washes.

The Nature Conservancy received funding from the Arizona Water Protection Fund Commission to restore the two ephemeral washes tributary to the Lower San Pedro River back to their natural state. The purpose of this wash restoration was to rectify considerable erosion problems across the San Pedro River floodplain. Sheet flow erosion rates at the site increased after a berm that directed wash flows around the agricultural field was breached during the 2006 flooding event and created chronic erosion and sedimentation conditions across lands cleared and leveled for agricultural purposes. The project involved decommissioning of a ditch and berm, re-contouring the transition between the uplands and the terrace, reconstructing two historic washes, and revegetation of native plant communities to stabilize all construction areas. Approximately 9 acres of stream channel were created and ~95 acres surrounding the new washes were hydroseeded with native seed mix. The seed was worked into the soil with a tractor pulled culti-packer in the uplands and with an OHV pulled flex harrow along the stream channels and banks. The site will be irrigated, mowed and monitored for at least three years to promote native vegetation establishment, to reduce competition from non-natives, and to document changes in erosion.

Disminución de erosión y sedimentación en la parte baja del río San Pedro mediante restauración hidrológica de arroyos efímeros modificados .

La organización Nature Conservancy obtuvo financiamiento de Arizona Water Protection Fund Commission para restaurar dos arroyos efímeros tributarios del río San Pedro a su estado natural. El propósito de la restauración fue corregir problemas de erosión de la llanura aluvial del río San Pedro. El índice de erosión laminar del sitio aumentó después que el bordo que permitía el riego del arroyo en la zona agrícola se lo llevó la corriente del 2006 causando bastante erosión y sedimentación afectando los terrenos agrícolas. El proyecto consistió en destruir el bordo y la zanja, definir de nuevo la transición entre la altiplanicie y el terraplén, reconstrucción de arroyos históricos, y reforestación de comunidades de plantas nativas para estabilizar todas las áreas de construcción. Aproximadamente 3.4 ha. del cauce del arroyo fueron creadas y ca. 40 ha. de los alrededores fueron sembradas con una mezcla de semillas nativas. La semilla se introdujo al suelo con un tractor empleando un quebra terrones "cultipacker" en las zonas elevadas y un OHV arrastrado a lo largo del canal del arroyo y bancos. El sitio será irrigado, podado y monitoreado por lo menos tres años para establecer especies nativas, reducir competencia de especies introducidas y documentar los cambios en erosión.

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Peloncillo Mountains ciénega restoration project. Cloverdale Ciénega was a vast desert marsh irrigated by a 10,000-acre watershed that is now in excellent condition. It was so large, in relation to its watershed size, that it was able to harvest the bulk of the runoff from a typical storm by super charging its alluvial storage. Down valley, wetland swales brought water to Cloverdale Creek, creating a perennial stream reach. This wetland complex has been degraded due to an old concrete dam, dozens of berms and a deep gully. The only perennial creek in the Peloncillo Mountains is now an arroyo and the ciénega is greatly reduced. The project goals were to restore a more natural hydrology to the watershed; restore riparian vegetation, and to protect and enhance the population of the frog. After careful planning we commenced work in spring 2010. We removed over 6000 cubic yards of dirt from levees and with 250 tons of boulders we constructed four diversions along the man-made gully. These structures were designed to allow storm flows to spread out over the entire width of the dried ciénega surface. The re-wetting of this surface will allow wetland plant communities to re-colonize what is now grassland and will provide enhanced habitat for the Chiricahua leopard frog (*Rana chiricahuensis*).

Proyecto de restauración de una ciénega en la Sierra Peloncillo. La Ciénega de Cloverdale fue un extenso humedal del desierto, alimentado por una cuenca de 5,000 has, que actualmente se encuentra en una condición excelente. Su gran extensión en relación con el tamaño de su cuenca le permitía aprovechar la mayor parte de los escurrimientos de las lluvias y sobre cargar su almacenaje aluvial. Valle abajo, las depresiones naturales llevaron agua al Cloverdale Creek, creando un riachuelo perenne. Este complejo de humedales se degradó debido a un antiguo dique de concreto, docenas de bordos y un gran barranco. El único riachuelo perenne en las Sierra Peloncillo es ahora un arroyo seco y la ciénega se ha reducido en gran medida. Las metas del proyecto son devolverle una hidrología más natural a la cuenca; restaurar la vegetación de la ciénega y proteger y aumentar la población de rana. Después de una planeación cuidadosa se empezó a trabajar en la primavera de 2010. Se removieron más de 5000 metros cúbicos de tierra de los diques y con 250 toneladas de rocas se construyeron cuatro desviaciones para el agua a lo largo del barranco excavado. Estas estructuras fueron diseñadas para permitir a las corrientes de las lluvias dispersarse a lo largo y ancho de la superficie seca de la ciénega. Agua en la superficie permitirá que las comunidades de plantas de la ciénega recolonizen lo que ahora es un pastizal y se mejore el hábitat para la rana chiricahua (*Rana chiricahuensis*).

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The future of restoration in the Sky Islands: Bringing volunteers, landowners, practitioners and agencies together to benefit wildlife and habitats in a global biodiversity hotspot. The Sky Island region of the Southwestern US and Northwestern México is recognized internationally as a biodiversity hotspot. Sky Island Alliance is a grassroots organization dedicated to the protection and restoration of this rich natural heritage of unique and rare species and habitats. We bring volunteers, landowners and agency personnel together to plan and implement riparian and upland restoration projects to protect desert, grassland and riparian wildlife and habitats. Four case studies of restoration projects are presented that can inform similar projects. First is a study of a planning project in the headwaters of the Santa Cruz River where a lack of communication between the project manager, adjacent landowners, and wildlife managers doomed its completion. Second is a study on an ongoing project in the Huachuca Mountains where man-made impoundments allowed bullfrogs to breed and along with un-natural rates of erosion have extirpated native aquatic species. Third is a study of non-native species control project in the Pajarito Mountains where in 2009 we initiated a collaborative landscape-level inventory and control program. Fourth is a study on upland restoration focusing on road density reductions and arroyo erosion control to protect the oak savannas and riparian areas of the Ciénega Creek Watershed.

El futuro de la restauración en las Islas Serranas: unir voluntarios, propietarios, profesionales y agencias para beneficiar la fauna y el hábitat en un área de importancia global por su biodiversidad. La región de las Islas Serranas del Suroeste de E.U. y Noroeste de México es reconocida internacionalmente como un área de importancia mundial por su biodiversidad. Sky Island Alliance es una organización local dedicada a la protección y restauración de esta rica herencia natural de hábitats y especies únicas y raras. Reunimos voluntarios, propietarios y personal de agencias para planear e implementar proyectos de restauración de ríos y tierras adyacentes para proteger desiertos, pastizales, hábitats y fauna ribereña. Se presentan cuatro casos de estudio de proyectos de restauración que pueden ilustrar proyectos semejantes. El primero es el estudio de un proyecto de planeación en el nacimiento del río Santa Cruz donde la falta de comunicación entre el encargado del proyecto, los propietarios vecinos y los encargados de fauna causó que éste fracasara. El segundo es un estudio de un proyecto en curso en la Sierra Huachuca donde la construcción de represas permitió la reproducción de la rana toro que junto con índices de erosión anormales han extirpado las especies acuáticas nativas. El tercero es un estudio de un proyecto de control de especies introducidas en la Sierra Pajarito donde en 2009 empezamos un inventario biológico y un programa de control. El cuarto es un estudio de restauración de tierras altas concentrado en reducir el número de caminos y la erosión de arroyos para proteger los pastizales, encinales y áreas ribereñas de la cuenca de Ciénega Creek.

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Walking the ciénegas of the Sky Island Region: Current condition and future potential. We describe current conditions and discuss restoration and long-term protection potential of a selected ciénegas of the region based on preliminary assessments. There is a scarcity of information, current or historical, on the ciénegas of the region and we hope to add to the renewed interest in and growing knowledge of their ecology, and their protection and restoration. Sky Island Alliance staff, volunteers, and collaborators have visited many historic ciénega sites and have performed assessments that ranged from intensive planning to short (1-2 days) investigations. These assessments have focused on two issues, what are the impacts affecting the system and what is the restoration potential? We have assessed, to one degree or another, a range of ciénega types from large (>200 acres) to small (<1 acre) associated with rivers, creeks, and spring and seep systems. Impacts include aquifer drawdown, draining, un-managed livestock grazing, invasive species of plants and animals, flow capture by roads, water developments, erosion such as arroyo cutting, and lack of management. Ciénegas discussed include upper and lower Cloverdale, Saracachi, Los Fresnos, St. David, San Simon, Animas Creek, Canelo Hills, Bog Hole, Ciénega Creek, plus other sites in the Burro, Peloncillo, Huachuca, Pinaleno, Galiuro, and Santa Rita Mountains.

Caminando por las ciénegas de la Región de las Islas Serranas: condiciones actuales y potencial. Según una evaluación preliminar se seleccionó un grupo de ciénegas para describir las condiciones actuales, discutir su restauración y el potencial de protección a largo plazo. Debido a que existe muy poca información actual o histórica de las ciénegas de la región, esperamos aumentar el renovado interés en las mismas y el conocimiento de su ecología, protección y restauración. Personal de Sky Island Alliance, voluntarios y colaboradores visitaron varias ciénegas históricas e hicieron evaluaciones que varían desde trabajos intensivos a investigaciones cortas de 1 o 2 días. Estas evaluaciones se concentraron en dos inquietudes: ¿Cuáles son los impactos afectando el sistema? y ¿Cuál es el potencial de restauración? Se han evaluado de una u otra forma, una gran variedad de ciénegas desde grandes (>80 has) a pequeñas (<0.5 has) asociadas con ríos, riachuelos, aguajes y sistemas de filtración. Los impactos incluyen descenso del acuífero, drenado, sobrepastoreo del ganado, especies invasoras de plantas y animales, corrientes de agua

en los caminos, infraestructura para uso del agua, erosión de las paredes de los arroyos y falta de manejo. Se discuten las ciénegas de Cloverdale alto y bajo, Saracachi, Los Fresnos, St. David, San Simón, Ánimas Creek, Canelo Hills, Bog Hole, Ciénega Creek, además de otros sitios en las Sierras Burro, Peloncillo, Huachuca, Pinaleno, Galiuro y Santa Rita.

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An organized toolbox: Choosing the appropriate tools and methods to support climate change adaptation. Resource managers face a confusing and often overwhelming plethora of evolving tools and methods for considering climate change in planning and management. Many require substantial investments in data gathering, analysis, or stakeholder engagement. Many address only pieces of the climate change adaptation challenge without clear interconnection. Irreducible uncertainties associated with climate change call for an iterative approach to risk management using a mix of tools and methods matched to the stage of risk management being addressed, the specific issues and time scales of relevance, the resources available for planning, and desired characteristics for stakeholder engagement. We integrated several organizing frameworks into an interactive 'toolbox', the Carpe Diem West Academy (carpediemwestacademy.org). It reviews and characterizes over 100 extant tools, training resources, and best practices useful for planners and managers. While developed specifically for water resources planning, it has broad applicability for management of natural areas, because water-related stresses pervasively affect achievement of natural and cultural resource objectives, and because many tools, themselves, have broad applicability. Shared learning is supported through a series of engaging webinars addressing specific questions of planners and managers. The toolbox also is useful for identifying gaps where additional tools, methods, or professional development training are needed.

Protocolo organizado: Cómo escoger las técnicas y métodos adecuados para la adaptación al cambio climático. El personal de manejo de recursos se enfrenta con complicadas y abrumadoras técnicas y metodologías siempre cambiantes al tratar de incluir el cambio climático en sus planes de manejo. Muchos requieren inversiones considerables para obtener información, analizarla, o la participación de los sectores interesados. Muchos sólo abarcan fracciones de la adaptación al cambio climático sin una clara interconexión. La incertidumbre inapelable asociada con el cambio climático requiere de una aproximación reiterativa en el manejo de riesgos empleando una mezcla de técnicas y métodos a la altura del problema que se está abordando, temas específicos y escala de tiempo relevante, los recursos disponibles para la planeación, y características ideales de los distintos sectores. Integramos varios marcos de referencia en un "protocolo" interactivo: la Carpe Diem West Academy (carpediemwestacademy.org). Aquí se compilan y caracterizan más de 100 técnicas, cursos de capacitación, y las mejores prácticas útiles para los encargados del programa de manejo. Aunque se diseñó para el manejo de recursos hídricos, se puede aplicar al manejo de áreas naturales, porque el estrés relacionado con el agua afecta en gran medida los objetivos del resto de los recursos naturales y culturales, además muchas técnicas se pueden aplicar independientemente a distintos problemas. Se promueve el aprendizaje compartido a través de seminarios por internet abordando preguntas específicas de los encargados de manejo. Este "protocolo" también es útil para identificar lagunas donde se necesiten nuevas técnicas, metodologías o capacitación profesional.

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The utility of PRISM precipitation estimates within the Madrean Archipelago. Precipitation is the primary driver for ecological processes across the Madrean Archipelago. Often researchers and managers must interpret monitoring observations, or assess potential climate change, across large areas based on a limited number of rain gauges. A potential additional source of information is the PRISM (Parameter-elevation Relationships on Independent Slopes Model) dataset (<http://www.prism.oregonstate.edu/>) available in the U.S. at both 4 km (free) and 800 m (priced) spatial and monthly temporal resolutions. Because so much of the precipitation in the Madrean Archipelago falls as short-duration, high-intensity convective thunderstorms during the North American Monsoon, it is unclear how to interpret the PRISM estimates, which do not reflect the spatial variability inherent in those storms. We compared measured values for a single gauge located in Tombstone and PRISM estimates of annual precipitation to the measured precipitation from 88 rain gauges for the 149 sq. km Walnut Gulch Experimental Watershed, 1999-2008. The mean error of area-weighted annual precipitation from a single gauge was -10%, with the greatest single year error of -37%. PRISM had corresponding errors of 9 and 30%. This preliminary analysis indicated that PRISM could complement limited observations to improve spatial and temporal understanding of precipitation for some research and management purposes.

Estimación de precipitación en el Archipiélago Madreño usando PRISM. El factor principal en procesos ecológicos del Archipiélago Madreño es la precipitación. Investigadores y administradores deben interpretar las observaciones del monitoreo, o evaluar el cambio climático potencial de grandes áreas basándose en un número limitado de pluviómetros. Una fuente adicional es la información de PRISM (por sus siglas en inglés, modelo de relación de parámetro-elevación en pendientes independientes <http://www.prism.oregonstate.edu/>) disponible en Estados Unidos en dos presentaciones 4 km (gratis) y 800 m (costo) de resolución espacial y con una resolución temporal mensual. Debido a que mucha de la precipitación en el Archipiélago Madreño cae en periodos cortos durante tormentas convectivas de gran intensidad durante el monzón norteamericano, la información del PRISM es difícil de interpretar, ya que no refleja la variabilidad espacial de las tormentas. Comparamos valores de un pluviómetro en Tombstone, además de estimaciones de precipitación anual del PRISM y las medidas de precipitación de 88 pluviómetros de los 149 km² de la estación experimental Walnut Gulch, de 1999 a 2008. El error medio de la precipitación anual ponderada de un

solo pluviómetro fue de -10%, mientras que el error mayor de un solo año fue de -37%. Los errores de PRISM fueron 9 y 30% respectivamente. Este análisis preliminar sugiere que PRISM podría complementar las observaciones limitadas para mejorar la comprensión de precipitación espacial y temporal, con fines de investigación y manejo.

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Potential climate change effects on vegetation types in the Sky Islands area. Climate change may have strong effects on the vegetation and associated habitats and human values in the Sky Islands area of southeastern Arizona. We connected a dynamic global vegetation model (MC1) to local state and transitions models (STMs) for major Sky Island vegetation types to better understand how changes in climatically driven vegetation potential and wildfire regimes might affect the local vegetation in the Sky Islands area. MC1 produces projections of potential future vegetation types and wildfire regimes under alternative climate scenarios, but does not generally consider detailed vegetation dynamics such as succession, growth, fire resistance, competition, and other factors. On the other hand, while available local STMs track the effects of disturbances, vegetation dynamics, and management on individual vegetation cover and structure combinations, STMs assume vegetation potential is static. We derived changes in vegetation potential and wildfire from MC1 under three different climate scenarios and incorporated them in a suite of local STMs. Our results suggest that climate-driven changes over the next 100 years could be dramatic, including substantial declines in coniferous forest area and large increases in warm-season (C4) grasslands. Our models also allow land managers and others to examine the possible effects of different vegetation management activities on future vegetation conditions given the three climate change scenarios.

Efectos potenciales del cambio climático en la vegetación de las Islas Serranas. El cambio climático puede afectar en gran medida la vegetación y hábitats asociados e inmuebles de las Islas Serranas del sureste de Arizona. Conectamos un modelo de vegetación mundial dinámico (MC1) con modelos locales y en transición (STMs) para los principales tipos de vegetación de las Islas Serranas, para entender como los cambios en vegetación causados por el clima, y cambio en el régimen de incendios forestales pueden afectar la vegetación local de las Islas Serranas. Los MC1 proyectan tipos de vegetación potencial en el futuro y el régimen de incendios bajo diferentes escenarios climáticos, pero no consideran procesos dinámicos detallados de la vegetación como sucesión, crecimiento, resistencia a fuego, competencia y otros factores. Por otro lado, aunque los modelos locales STMs siguen los efectos de disturbio, dinámica de la vegetación, manejo de cobertura vegetal por especie y combinaciones de estructura, los STMs asumen que el potencial vegetal es estático. Derivamos cambios en la vegetación potencial y los incendios de MC1 bajo tres diferentes escenarios climáticos y los incorporamos a los STMs locales. Los resultados sugieren que los cambios causados por el clima en los próximos 100 años pueden ser drásticos, con considerable disminución del área de bosques de coníferas y un gran incremento en pastizales (C4) de estación cálida. Nuestros modelos permiten que el personal de manejo de recursos y otros, examinen los posibles efectos de actividades de manejo bajo condiciones futuras de vegetación en tres escenarios del cambio climático.

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Floristic analysis of a vegetation island and biological corridor in Sonora, Mexico. We performed a floristic study of the vegetation islands on the mountain town of Montezuma, Sonora. From August to December 2011, the relevé method was used on ranches El Rodeo and Basora. The sites are located ca. 900 m elevation in foothills thornscrub. We collected a total of 85 species in 70 genera and 30 families. The species were identified through expert advice, literature, and comparison with specimens in the Herbarium of the Universidad de Sonora Herbarium (USON) in Hermosillo. Specimens were deposited into USON. The best represented families are Asteraceae, Convolvulaceae, Fabaceae, and Solanaceae. The study area is a transition zone between subtropical thornscrub and Sierra Madrean forest elements, making it an important biological corridor for the Sky Islands. It was found that the loss of flora is high due to changing land use, mainly the invasion of buffelgrass (*Pennisetum ciliare*). Representative species of the area as *Zinnia zinnioides*, *Ipomoea cristulata*, *I. hederacea*, and *Abutilon* can be replaced by species that have adapted to local new conditions.

Análisis florístico de las islas de vegetación y corredor biológico de la sierra media de Sonora, México. Se realizó un estudio florístico en las islas de vegetación de la sierra media del municipio de Moctezuma, Sonora. De agosto a diciembre de 2011, se realizaron tres recorridos de campo usando el método de relevé en los ranchos El Rodeo y Básora. Los sitios son ubicados ca. 900 msnm en matorral espinoso. Se recolectaron un total de 85 especies en 70 géneros y 30 familias. Las especies fueron identificadas mediante la asesoría de expertos, bibliografía y herbario USON. Ejemplares fueron depositados en el herbario de la Universidad de Sonora. Las familias mejor representadas son Asteraceae, Convolvulaceae, Fabaceae y Solanaceae. El área de estudio es una zona de transición del matorral subtropical y elementos del bosque madrense, que lo convierten en un importante corredor biológico para las Islas Serranas. Se encontró que la pérdida de flora es alta debido al cambio de uso de suelo, principalmente por la invasión de zacate buffel (*Pennisetum ciliare*). Especies representativas de la zona como *Zinnia zinnioides*, *Ipomoea cristulata*, *I. hederacea* e *Abutilon* pueden ser desplazadas por especies que se han ido adaptando a las condiciones nuevas del lugar.

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Association between nurse plants and saguaros (*Carnegiea gigantea*) in the western Sonora. The objectives are to determine nurse species associated with the saguaro, as well as the plants in the patch, and the mortality of nurse plants. Because the presence of termites on the green tissue of the saguaro has been linked, the existence of protection against termites in three sites, located in the western Sonora, was studied. In each site a transect using the quadrant point method was performed, where data was taken on the closest saguaros, organic material coverage around it, termite activity in them, the conditions of its nurse plants, the floristic composition, and the dimensions of the associated patch of vegetation. Data on 56 saguaros showed the most common nurse plants were *Larrea tridentata*, *Olneya tesota*, *Ambrosia deltoidea*, and *Parkinsonia microphylla*. Twenty-one (21) species were found distributed in different patches associated with the saguaro, where *O. tesota* and *P. microphylla* showed the most species diversity. The mortality of the nurse plants is associated with the number of plants located under its canopy and its size. The termite activity was in saguaros with little organic material. The positive interactions permit for the saguaro populations in this region to be healthy. It is the first work to document the decrease of termite invasion of live saguaro tissue.

Asociación de las plantas nodrizas con el Sahuaro (*Carnegiea gigantea*) en la región oeste de Sonora. Los objetivos son determinar especies nodrizas asociadas al sahuaro, así como la diversidad de plantas en el parche y la mortalidad de plantas nodrizas. Dado que se ha asociado la presencia de termitas sobre tejido verde de sahuaro, se estudió la existencia de protección contra termitas en tres sitios ubicados en la región oeste de Sonora. En cada sitio se realizó un transecto utilizando el método del punto cuadrante, donde se tomaron datos de los sahuaros más cercanos, cobertura de materia orgánica alrededor, actividad de termitas en sahuaros, condición de su nodriza, composición florística y dimensiones del parche de vegetación asociado. Se muestrearon 56 sahuaros, las nodrizas más comunes fueron *Larrea tridentata*, *Olneya tesota*, *Ambrosia deltoidea* y *Parkinsonia microphylla*. Se encontraron 21 especies distribuidas en diferentes parches asociados al sahuaro, donde *O. tesota* y *P. microphylla* presentan mayor diversidad de especies. La mortalidad de la nodriza está asociada al número de plantas de sahuaro establecidas bajo su dosel y tamaño. La actividad de termitas estaba en sahuaros con poca materia orgánica. Las interacciones positivas permiten que poblaciones del sahuaro en esta región estén saludables. Es el primer trabajo que documenta la disminución de la invasión de termitas a los tejidos vivos de sahuaro.

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Wide range of functional attributes in the Central Sonora flora: a diversity yet to be explored. Even though the Sonoran desert is not considered the desert with more species richness, it has been documented in multiple occasions that it has the most diversity of growth forms of North America. It is unknown if in addition to high growth form diversity there could also be high functional diversity in this Desert. We characterized the ecophysiological functional attributes related to photosynthetic capacity, stomata conductance, transpiration, and resources (water and nitrogen) use efficiency, as well as leaf area morphostructural attributes and nitrogen content in leaves of 51 species of the arid and semiarid region of central Sonora. We found a wide range in the studied attributes even higher in comparison with species studied worldwide, which is confirmation of high functional diversity. This study presents evidence of high functional diversity in the Sonoran Desert that is waiting to be described and documented.

Gran amplitud en el rango de atributos funcionales encontrada en la flora de la Región Central de Sonora: una diversidad por ser explorada. En el Desierto Sonorense, aunque no sea este el desierto con mayor riqueza de especies de plantas, se ha documentado en repetidas ocasiones que éste posee la mayor diversidad en cuanto a formas de crecimiento en Norteamérica. Se desconoce si además de esta alta diversidad, este desierto pudiera también albergar una alta diversidad funcional. En este trabajo se caracterizaron los atributos funcionales ecofisiológicos de capacidad fotosintética, conductancia estomática, transpiración y eficiencia de uso de recursos (agua y nitrógeno), así como los atributos morfoestructurales de área foliar específica y contenido foliar de nitrógeno en 51 especies que habitan en las zonas áridas y semiáridas de la Región Central de Sonora. En tan solo estas especies se encontró en los rangos de todos los atributos medidos una amplitud similar e incluso mayor a la reportada para todas las especies del mundo en las que han sido estudiados dichos atributos, lo cual refleja una alta diversidad funcional. Esta gran amplitud no es algo comúnmente encontrada en otras regiones del mundo. Este trabajo presenta evidencia de la alta diversidad funcional del Desierto Sonorense en espera de ser descrita y documentada.

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Planning the future on the Coronado National Forest. Most U.S. Sky Island mountain ranges are public lands managed by the U.S. Forest Service. The majority (20) are found on 12 Ecosystem Management Units of the Coronado National Forest. The Coronado is currently engaged in two multi-year processes - Land and Resource Management Planning, and Travel Management Planning - as are all U.S. national forests. These public processes will determine future management of, and impacts to, these Sky Island ranges and their hydrology, wildlife, and opportunities for quite recreation, as well as cultural, geologic, scenic, historic, and vegetation resources. Major challenges to good management planning outcomes include shrinking Forest Service budgets, laws and regulations that do not keep pace with science or community values, climate change,

and a 20th century paradigm that pushes Multiple Use into as many areas as possible. Some recent initiatives such as FireScope and the Pinaleno Ecosystem Restoration Project provide a useful model for agency response to public input and the use of science to solve complex challenges.

Planificar para el futuro del Bosque Nacional Coronado. La mayoría de las Islas Serranas de Estados Unidos son áreas naturales manejadas por el Servicio Forestal de Estados Unidos. La mayoría (20) se encuentran en 12 Unidades de Manejo de Ecosistemas del Bosque Nacional Coronado. El Coronad, igual que todos los bosques nacionales en EU, está trabajando en dos proyectos plurianuales: Plan de Manejo de Tierra y Recursos y Plan de Manejo de Visitantes. Estos procesos con la ciudadanía determinarán el manejo futuro e impacto en estas Islas Serranas su hidrología, y flora y fauna, así como oportunidades de recreación, culturales, geológicas, escénicas, históricas, y de uso maderable. Los grandes retos para obtener buenos resultados con el plan de manejo son: reducción del presupuesto del Servicio Forestal, leyes y normativas no actualizadas con la ciencia o intereses de la comunidad, cambio climático y el paradigma del siglo XX que pide usos múltiples para la mayoría de áreas. Algunos programas nuevos como FireScope y el proyecto de restauración del ecosistema Pinaleno son modelos de cómo la atención de las agencias a la aportación del público y el uso de la ciencia pueden resolver problemas complejos.

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Si se puede! A decade of restoration, research, and science on cross-border private lands. The Cuenca Los Ojos Foundation owns and/or manages more than two hundred thousand acres in southeast Arizona and northeast Sonora. Much of the foundation's focus has been on restoring landscapes and wildlife populations that have been damaged to varying degrees by over utilization of natural resources and the cascading effects of this over utilization. Initial work on these lands was focused on both passive and active restoration. Over the past decade, Cuenca Los Ojos lands have attracted almost a hundred individual researchers from dozens of universities, NGO's, as well as private investigators. These lands have become outdoor laboratories for the study of natural processes, specific species, and ecosystem services. In an attempt to better understand these processes and services, we recently conducted follow-up surveys and interviews with scientists who had worked here. Survey results support the status of these lands as biodiversity hotspots and providers of valuable ecosystem services. Results that follow restoration activities document the return of several locally extirpated species, resurgence of grass cover, and re-wetting of streams and ciénegas.

¡Si se puede! Una década de restauración e investigación científica en tierras de propiedad privada a través de la frontera. Más de 80, 937 has pertenecen o son manejadas por la fundación Cuenca Los Ojos en el sureste de Arizona y noreste de Sonora. La mayor parte del trabajo de la fundación se dedica a restaurar el paisaje y poblaciones de fauna y flora que han sido degradadas en varios niveles por la sobreexplotación de los recursos naturales y efectos cascada de la misma. Los trabajos iniciales incluyeron tanto métodos pasivos como activos de restauración. Casi cien investigadores de docenas de universidades, ONG's y del sector privado han visitado Cuenca Los Ojos, durante la última década. Estas tierras se han convertido en un laboratorio para el estudio de procesos naturales, especies específicas y servicios ecosistémicos. Con el intento de entender mejor estos procesos y servicios, entrevistamos a los investigadores que han realizado sus proyectos aquí. El resultado de estas encuestas confirma el estatus de estas tierras como centro de biodiversidad y fuente de invaluable servicios ecosistémicos. Resultados del trabajo de restauración incluyen el regreso de varias especies extirpadas localmente, resurgimiento de la cobertura de zacates, y agua en arroyos y ciénegas.

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Pre-Columbian Agaves in Arizona: a new way of looking at species and their landscapes. The importance of agaves to Mesoamerica and its cultures has long been recognized, providing food, fiber and beverage. However, their significance to these cultures has overshadowed and distorted the plants' role for indigenous peoples north of the U.S. - Mexico border. Pre-Columbian farmers cultivated several species of agave in Arizona dating to at least A.D. 600, including *Agave murpheyi*, *A. delamateri*, *A. phillipsiana*, *A. parryi* var. *parryi*, *A. parryi* var. *huachucensis*, and two undescribed species. Because of their longevity and primarily asexual reproduction, relict agave clones have persisted in the landscape to the present, providing an opportunity to study pre-Columbian nutrition, trade, migration and agricultural practices. Additionally, these remnant clones present a rare opportunity to examine cultivars virtually unchanged since they were last cultivated within a prehistoric cultural context. At least three, *A. murpheyi*, *A. delamateri*, and *A. phillipsiana*, are most likely not native to Arizona, probably having originated in northern Mexico and traded as far north as Grand Canyon. These discoveries underscore the necessity of viewing landscapes and some plant species from a cultural, rather than "natural," perspective that may help discern potential cryptic species veiled by more traditional taxonomic treatments. Understanding these plants and their ecological/cultural roles requires interdisciplinary collaboration between botanists and archaeologists.

Agaves precolombinos en Arizona: un nuevo enfoque en especies y su paisaje. La importancia del agave en la cultura mesoamericana es ampliamente reconocida por ser fuente de alimento, fibra y bebida. Sin embargo, esa importancia cultural a opacado y distorsionado el papel de estas plantas para los indígenas al norte de la frontera entre México y E.U.. Labradores precolombinos cultivaban varias especies de agave en Arizona por lo menos desde el año 600 DC., como son: *Agave murpheyi*, *A. delamateri*, *A. phillipsiana*, *A. parryi* var. *parryi*, *A. parryi* var. *huachucensis* y dos especies no descritas. Debido a su longevidad y reproducción asexual, relictos de clones de estos agaves han persistido en el paisaje, permitiendo estudiar nutrición, intercambio, migración y prácticas agrícolas de culturas precolombinas. Aunado a esto los clones presentan la oportunidad de examinar cultivares virtualmente prístinos ya que fueron cultivados por última vez en el contexto prehistórico. Al menos *A. murpheyi*, *A. delamateri* y *A. phillipsiana*, no son nativos de Arizona, tal vez son del norte de México y se intercambiaron entre culturas hasta el Gran Cañón. Estos descubrimientos enfatizan la necesidad de estudiar el paisaje y algunas especies de plantas con una perspectiva cultural

en lugar de “natural” y así identificar especies crípticas encubiertas por tratamientos taxonómicos tradicionales. El estudio de éstas plantas así como su papel ecológico y cultural requiere de colaboración interdisciplinaria entre botánicos y arqueólogos.

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The 2011 Wallow Fire: An archeologists perspective on BAER work. The 2011 Wallow Fire in Arizona and New Mexico burned over 553,456 acres on the Apache-Sitgreaves and Gila National Forests with associated private and Tribal lands. Archeological work was to first protect cultural resources then move into BAER (Burned Area Emergency Rehabilitation) work for saving cultural resources after the fire. Our work on BAER was to first find sites affected by the Wallow Fire then determine damage and assess mitigation for protecting them. This was to protect from damage by debris flows or other natural factors with the upcoming monsoon season in Northeastern Arizona. Since all fires are different, the Wallow Fire allowed us to work on what we can do to protect sites quickly with little resources on a fire of unprecedented size using skills learned in BAER work from previous large fires across the country.

Incendio Wallow 2011: una perspectiva arqueológica de BAER. En el 2011 el incendio forestal Wallow en Arizona y Nuevo Mexico afectó más de 224,000 ha. en los Bosques Nacionales Apache-Sitgreaves y Gila, así como terrenos privados y pertenecientes a tribus. El trabajo arqueológico primero se enfocó en proteger los recursos culturales y segundo realizar el trabajo de BAER (por sus siglas en inglés, rehabilitación de emergencia de áreas quemadas) de proteger recursos culturales después del incendio. El trabajo en BAER consistió en encontrar zonas afectadas por el incendio Wallow, determinar el daño y evaluar la mitigación necesaria para protegerlas. La protección fue prevenir derrumbes u otros factores naturales que pudieran causar las lluvias del monzón en el noreste de Arizona. Ya que todos los incendios son diferentes, el incendio Wallow permitió que se trabajara rápido en la protección de sitios con recursos escasos empleando técnicas adquiridas en incendios anteriores en BAER.

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A pre and post-fire comparison of vegetation in the Santa Catalina Mountains. In 1995 vegetation plots were sampled along a series of transects within five of the largest mountain ranges in the sky islands. Since then many of these areas have burned. To take advantage of this unique opportunity, in 2009 the vegetation plots in the Santa Catalina Mountains were re-measured. These plots burned in 2002 and 2003 as part of the Bullock and Aspen fires, respectively. The objectives of this study were to (1) asses how stand structure affected burn severity; (2) determine the impact of burn severity on stand structure and (3) asses post-fire succession patterns. Stand structure is critical in forest and fire ecology. Stand structure influences fire behavior particularly crown fires and is also directly related to succession and therefore a major part of state-transition models. Despite the importance of stand structure, little is known about the relationship between fire and stand structure in the sky islands. Our results suggest that some previously forested areas have been converted to shrub fields as a result of high burn severity; however, the majority of the plots sampled in 1995 experienced low to moderate severity fire. This information will provide valuable information that managers can use in managing post-fire landscape mosaics.

Una comparación de vegetación antes y después de incendios en la Sierra Santa Catalina. Se hicieron muestreos en cuadrantes de vegetación en una serie de transectos ubicados en 5 de las cordilleras más grandes de las Islas Serranas en 1995. Desde entonces muchas de estas áreas se han quemado. Para aprovechar esta oportunidad única, en 2009 los cuadrantes de vegetación en la Sierra Santa Catalina se midieron de nuevo. Estas parcelas se quemaron en 2002 y 2003 en los incendios Bullock y Aspen, respectivamente. Los objetivos de esta investigación fueron (1) evaluar como la estructura forestal afectó la severidad del incendio; (2) determinar el impacto de la severidad del incendio en la estructura forestal y (3) evaluar patrones de sucesión después de incendios. La estructura forestal es crítica en la ecología forestal y del fuego. La estructura forestal influye el comportamiento del fuego, especialmente fuegos de copas, y también se relaciona directamente con la sucesión y por tanto es una parte importante de los modelos de transición. A pesar de la importancia de la estructura forestal, se conoce poco sobre la relación entre el fuego y la estructura forestal en las islas serranas. Nuestros resultados sugieren que algunos rodales forestales se han convertido en matorrales por causa de incendio muy calientes; sin embargo, la mayoría de las parcelas muestreadas en 1995 experimentaron incendios de intensidad baja o moderada. Esta información será muy útil en el manejo de paisajes afectados por el fuego.

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Preliminary List of flying mammals in the Ajos-Bavispe National Forest Reserve and Wildlife Refuge, Sonora: synthesis. The generation of information on bat communities, including their composition, abundance, distribution and ecology, can support management programs in protected areas, and also provide information and initiatives for the designation of new protected areas. From the year 2010 and 2011 monitoring was done within a Sky Island, called Sierra de los Ajos, which is part of the Ajos-Bavispe reserve. During this period of time, we had recorded a total of eight species (*Myotis californicus*, *Myotis auriculatus*, *Myotis volans*, *Myotis thysanodes*, *Lasiurus cinereus*, *Lasiurus blossevillii*, *Eptesicus fuscus*, and *Choeronycteris mexicana*) in riparian and oak-pine forests. This preliminary list can speculate about the good health of the ecosystem

in this protected area and provides good guidelines for carrying out monitoring in other sky islands within the same protected area: La Madera, El Tigre, Buenos Aires, and La Púrica. The intention of this paper is to use the bat as a tool to assess the degree of conservation of these Sky Islands, because they are abundant, diverse, relatively easy to monitor and there are low-cost materials used for study. In the end, presence and/or absence of bat communities will allow conservation and management decisions in the short and long term in this important protected area.

Listado preliminar de mamíferos voladores en la Reserva Forestal Nacional y Refugio Fauna Silvestre Ajos-Bavispe: síntesis. La generación de información de las comunidades de murciélagos, su composición, abundancia, distribución y ecología, permite sustentar los programas de manejo en áreas naturales protegidas, y proporcionan datos e iniciativas para la designación de nuevas áreas de protección. De 2010 a 2011 se realizó un monitoreo en la Sierra de Ajos que forma parte de Ajos Bavispe, registrándose un total de ocho especies (*Myotis californicus*, *Myotis auriculus*, *Myotis volans*, *Myotis thysanodes*, *Lasiurus cinereus*, *Lasiurus blossevillii*, *Eptesicus fuscus* y *Choeronycteris mexicana*), en bosques de galería, y bosques de encino-pino. Este listado preliminar permite especular sobre el buen estado de salud del ecosistema en esta área natural protegida y da pauta para llevar a cabo monitoreo en otras Islas Serranas en la misma área natural protegida: Sierra La Madera, El Tigre, Buenos Aires y La Púrica. La intención de este trabajo es utilizar a los quirópteros como una herramienta para evaluar el grado de conservación de estas Islas Serranas; ya que son abundantes, diversos y relativamente fáciles de monitorear, con costos bajos en el material para su estudio. La presencia y/o ausencia de comunidades de murciélagos permitirá tomar decisiones de manejo y conservación a corto y largo plazo en esta área natural protegida.

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Changes in a lizard assemblage at an ecotone in southeastern Arizona. The Madrean Archipelago and its associated valleys have the highest diversity of lizards in the United States. This is due to a convergence of ecoregions in an area that provides excellent environmental conditions for life history needs of terrestrial ectotherms. The study area, near Safford, Arizona, is known to have about 20 species of sympatric lizards, although only about one-half are common. The lizard community is typical of Sonoran and Chihuahuan deserts, semi-desert grasslands, and lower Madrean and boreal woodlands. It has recently been suggested that lizard species are expected to decline globally due to climate change and other factors. The study site is located at an ecotone between desert and grasslands in a foothills situation, as ecotones are expected to be sensitive to environmental change. Study objectives were to (1) assess the baseline lizard community and (2) detect changes in the lizard assemblage over time. In 2003, 2010, and 2011, about 4,000 lizards were recorded on transects. Early data returns suggest that adaptable desert and grassland species are common, while other, more specialized or mesic species appear to be trending toward a decline. Lizards may be better bio-indicators of environmental change than the plant communities in which they occur.

Cambios en un ensamble de lagartijas en un ecotono del sureste de Arizona. El Archipiélago Madreño y sus valles tienen la más alta biodiversidad de lagartijas en Estados Unidos. Esto se debe a la convergencia de eco regiones en una zona que posee condiciones ambientales excelentes para el ciclo de vida de organismos ectotérmicos terrestres. El área de estudio, cerca de Safford, Arizona, tiene aproximadamente 20 especies de lagartijas simpátricas, aunque sólo alrededor de la mitad son comunes. La comunidad de lagartijas es típica de los Desiertos Sonorense y Chihuahuense, praderas semidesérticas y bosques Madreños y boreales más bajos. Recientemente se publicó que se espera una disminución mundial de lagartijas por el cambio climático y otros factores. El sitio de estudio está ubicado en un ecotono entre desierto y pastizal en el piedemonte, ya que se espera que los ecotonos sean sensibles al cambio climático. Los objetivos del estudio fueron (1) evaluar la comunidad de lagartijas y (2) detectar cambios en el ensamble de lagartijas. En 2003, 2010 y 2011, cerca de 4,000 lagartijas se documentaron en los transectos. Los primeros datos sugieren que las especies adaptables de los desiertos y los pastizales son comunes, y parece ser que especies más especializadas o méxicas van en declive. Las lagartijas pueden ser mejores bioindicadores del cambio ambiental que las comunidades vegetales donde ocurren.

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What do we know of the Insects of Sonora, México? The insects reported from the Mexican state of Sonora are limited given its area and diversity, with over-representation of several orders. Of the records in the Madrean Archipelago Biodiversity Assessment (MABA) database, much of which is from records of the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO), there are reported a total of 10,341 insect specimen records. Of these records, 65% are Lepidoptera, 12% are Odonata and 9% are Hymenoptera; a typical collection bias (butterflies and dragonflies) for poorly collected regions. Two of most diverse insect orders, Coleoptera and Diptera, together represent less than 5% of the present database, of which 70% are scarabs and aquatic beetles. A latitudinal analysis of the butterfly fauna will be presented; the trends of which, may be indicative of other insect taxa. Clearly, international cooperation between scientists in México and the United States is necessary to coordinate new collection efforts and share systematic knowledge of the insects of Sonora, and specifically their Sky Islands.

¿Qué sabemos sobre los insectos de Sonora, México? Los insectos reportados del estado de Sonora son insuficientes dado su área y diversidad, y sobre cargados en varios órdenes. De los registros de la base de datos MABA (Evaluación de la biodiversidad del Archipiélago Madreño), la mayoría de CONABIO (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad) se reportan un total de 10,341 registros de ejemplares de insectos. De estos registros, 65% corresponden a Lepidoptera, 12% a Odonata y 9% a Hymenoptera, un sesgo de colecta típico (mariposas y libélulas) para regiones muy poco colectadas. Coleoptera y Diptera, dos de los órdenes más diversos, juntos representan menos del 5% de la actual base de datos y de éstos el 70% corresponde a escarabajos e invertebrados acuáticos. Se presentará un análisis latitudinal de la fauna de mariposas, donde las tendencias pueden ser indicadoras de otros taxones de insectos. Es evidente que se necesita una cooperación

internacional entre investigadores de México y E.U. para coordinar nuevos esfuerzos de colecta y compartir el conocimiento sistemático de los insectos de Sonora, y en especial de sus Islas Serranas.

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Phylogeography of Yarrow's Spiny lizard: What didn't happen in the Holocene. Estimates from radiocarbon-dated packrat middens indicate that the high elevation woodland communities of the Madrean Sky Islands were continuous as recently as 8,000 to 12,000 years ago. A number of population studies on a diverse collection of taxa have investigated the extent to which the Madrean Sky Island system has limited gene flow among mountain ranges. The results of several of these studies indicate that population divergences may be more ancient than the Holocene. Yarrow's spiny lizards, *Sceloporus jarrovi*, were sampled from eight sites representing seven mountain ranges. DNA sequences from the lizards were used to reconstruct their evolutionary relationships and estimate the ages of the populations. The findings of these analyses indicate that the sky island populations of *S. jarrovi* have been isolated for hundreds of thousands of years and did not experience gene flow during the last woodland expansion.

Filogeografía de la lagartija *Sceloporus jarrovi*: Lo que no pasó en el Holoceno. Estimaciones de paleomadriguera de roedores del género *Neotoma* fechadas con radiocarbono indican que las comunidades forestales en elevaciones altas de las Islas Serranas Madreñas fueron continuas hasta hace como 8.000 a 12.000 años. Varios estudios de población en diversos grupos taxonómicos han investigado hasta qué punto las Islas Serranas Madreñas ha limitado el flujo genético entre cordilleras. Resultados de estos estudios indican que las divergencias de las poblaciones son más antiguas que el Holoceno. Se estudiaron lagartijas *Sceloporus jarrovi* en ocho sitios que representan siete cordilleras. Las secuencias de ADN de las lagartijas se usaron para reconstruir sus relaciones evolutivas y calcular las edades de las poblaciones. Los resultados de los análisis indican que las poblaciones de *S. jarrovi* de las Islas Serranas han estado aisladas por cientos de miles de años y no experimentaron el flujo genético durante la última expansión de los bosques.

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Vegetation monitoring on semi-arid grasslands ungrazed by domestic livestock. The Research Ranch is an 8000 acre sanctuary and research facility in the semi-arid grasslands of southeastern Arizona, USA. Cattle were removed from the property in 1968 to provide a reference area by which various land uses such as grazing and exurbanization could be evaluated. Vegetation transects were established in 2000 and 2003 on several ecological sites in Major Land Resource Area 41. This monitoring program has tracked changes after wildfires and during drought. Trends associated with non-native, invasive species, particularly *Eragrostis lehmanniana* (Lehmann lovegrass) and *E. curvula* (Boer lovegrass) have been documented. For example, in an 8-year span, the frequency of Lehmann lovegrass on one loamy upland site grew from 1% to 60% at the expense of the native *Eragrostis intermedia* (Plains lovegrass) and *Bouteloua gracilis* (Blue grama). Results from monitoring provides feedback to Audubon personnel in the management of the property and are shared with other land managers to help tease apart the effects of grazing and other land use actions from the effects of climate.

Monitoreo de vegetación en praderas semiáridas libres de ganado. La estación biológica Appleton-Whittell es una reserva de 3,237 has y un centro de investigación en las llanuras semiáridas del sureste de Arizona, E.U. Se removió el ganado en 1968 para tener una referencia para evaluar cambios de uso del suelo como el pastoreo y la urbanización previos. Se establecieron transectos de vegetación en varios sitios ecológicos de Major Land Resource Area 41, durante 2000 y 2003. Este programa de monitoreo ha registrado cambios después de incendios y durante las sequías. Se han documentado los efectos de las especies introducidas e invasoras, especialmente *Eragrostis lehmanniana* y *E. curvula*. Por ejemplo, en un lapso de 8 años, la frecuencia de *E. lehmanniana* en una altiplanicie con suelo franco aumentó de 1% a 60% a expensas de los zacates nativos *Eragrostis intermedia* y *Bouteloua gracilis*. Los resultados del monitoreo sirven al personal de Audubon en la administración de la parcela y se comparten con otros administradores de tierras para ayudar a distinguir los efectos del pastoreo y otros usos del suelo de los efectos del cambio climático.

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Impacts of wildfire on wildlife in Arizona: a synthesis. Due to a century of fire suppression practices, the Madrean Archipelago regions in Arizona have accumulated excessive fuel loads, which increase wildfire sizes, intensities, and frequencies. These drastic changes in forest ecosystems can either benefit or adversely affect wildlife species. Therefore, it is imperative to understand how wildlife species react to such ecosystem changes after wildfires in both the short-term and long-term time periods. I will examine scientific literature to determine wildlife distribution, abundance, elevational migration, and behavioral changes (i.e. how wildlife use resources post-fire). Understanding the impacts of wildfire-induced habitat fragmentation and creation of edge effects on wildlife species will provide us information about overall forest condition and forest management practices.

Síntesis del impacto de incendios en la fauna de Arizona. Debido a un siglo de supresión de incendios, las regiones del Archipiélago Madreño en Arizona han acumulado combustible excesivo que aumenta el tamaño, intensidad y frecuencia de incendios. Estos cambios drásticos en los ecosistemas forestales pueden beneficiar o perjudicar la fauna silvestre. Por eso, es imperativo entender como la fauna reacciona a tales cambios ecosistémicos después de los incendios a largo y corto plazo. Analizaré la literatura científica para determinar la distribución, la abundancia, la migración altitudinal y los cambios de conducta (ej. uso de recursos después del incendio) de la fauna. Entender los impactos de la fragmentación y la creación de efectos de borde inducidos por los incendios en la fauna silvestre aportará información sobre la condición general del bosque y prácticas de manejo forestal.

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It's lonely at the top: Endemic biodiversity at risk to loss from climate change. Climate change is a serious immediate and long-term threat to wildlife species. State and federal agencies are working with universities and non-government organizations to predict, plan for, and mitigate such uncertainties in the future. Endemic species may be particularly at risk as climate-induced changes impact their limited geographic ranges. The Madrean Archipelago is characterized by high levels of endemism, natural fragmentation, and increasingly poor connectivity among the mesic montane islands within an arid matrix of low elevation deserts and grasslands. The region already has experienced an increase in temperature and this trend is predicted to accelerate over the remainder of the century. We assessed patterns of endemism and elevational distribution of terrestrial vertebrates within the Madrean Archipelago. We examined incremental temperature increases and determined how much endemic wildlife biodiversity is at risk to be lost from montane islands due to elevational and geographic restrictions. Endemism of non-volant and smaller bodied species is greater than for more vagile forms. Taxa also differ in their susceptibility to the impacts of climate change. We review the levels of risk, assess patterns of concern among the vertebrates, and discuss the implications of climate change on the endemic vertebrate fauna of the region.

Soledad en la cima: La biodiversidad endémica en riesgo de perderse por el cambio climático. El cambio climático es una amenaza seria y a largo plazo para las especies de flora y fauna. Agencias estatales y federales están trabajando con universidades y organizaciones no gubernamentales para predecir, prepararse, y mitigar tales incertidumbres en el futuro. Las especies endémicas particularmente estarán en riesgo cuando cambios en el clima afecten sus limitadas áreas de distribución. El Archipiélago Madreño se caracteriza por niveles altos de endemismo, fragmentación natural y una baja conexión entre las sierras montañosas mésicas en la matriz árida de pastizales y desiertos bajos. La región ya ha experimentado un aumento de temperatura y se predice que esto se acelere durante el resto del siglo. Evaluamos patrones de endemismo y distribución en un rango de elevación de vertebrados terrestres del Archipiélago Madreño. Analizamos incrementos graduales de temperatura y determinamos cuanta biodiversidad de fauna endémica está en peligro de perderse de las islas montañosas por restricciones altitudinales y geográficas. El endemismo es más común en las especies no-volantes y más pequeñas que en las formas más móviles. Los taxones también difieren en su vulnerabilidad a los impactos del cambio climático. Examinamos y evaluamos los niveles de riesgo de los vertebrados y analizamos las implicaciones del cambio climático en la fauna vertebrada endémica de la región.

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Feline monitoring in Sierra La Madera, Municipio de Moctezuma, Sonora, Mexico. This work was completed in the region known in Sierra La Madera, Fracción 5 of the Reserva Forestal Nacional y Refugio de Fauna Silvestre Sierra de Ajos-Bavispe Spanning an area of 97, 542.74 has, which in recent years has been influenced by ranching and illegal hunting, it is necessary to know the current biological state and abundance of the felines of the area. Monitoring efforts rely on the use of 20 camera traps that were distributed in several places in La Sierra, for three different periods from August to December 2011. During the first period three records of mountain lion (*Puma concolor*), and three records of bobcat (*Lynx rufus*) were obtained. During the second period, seven records of mountain lion and two records of bobcat were obtained. When monitoring is complete it will be necessary to obtain prey abundance and feline activity patterns.

Monitoreo de felinos en Sierra La Madera, Municipio de Moctezuma, Sonora, México. El presente trabajo se realizó en la región conocida como Sierra la Madera, Fracción V de la Reserva Forestal Nacional y Refugio de Fauna Silvestre Sierra de Ajos-Bavispe. Abarca una superficie de 97, 542.74 ha, que en los últimos años han tenido influencia por ganadería y cacería ilegal, es necesario conocer el estado biológico actual y la abundancia de felinos del área. El monitoreo está basado en el uso de 20 cámaras trampa, distribuidas en varios puntos de la Sierra, en tres campañas de agosto a diciembre de 2011. Durante la primera campaña se obtuvieron tres registros de puma (*Puma concolor*) y tres registros de gato montés (*Lynx rufus*). En la segunda campaña se obtuvieron siete registros de puma y dos registros de gato montés. Al finalizar el monitoreo se estima obtener abundancia de presas y patrones de actividad de felinos.

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Assessing and addressing ecological water needs in Arizona. The University of Arizona Water Resources Research Center (WRRC) has published two technical documents from a project to assess Arizona's environmental water needs. The Arizona Environmental Water Needs Assessment (AzEWNA) Report and the Arizona Environmental Water Needs Assessment Methodology Guidebook for the first time explore and synthesize efforts to quantify the water needs of river systems in Arizona. The Report summarizes the state of knowledge about environmental water needs, explores the information gaps and contains maps and graphics to help readers visualize the extent of the inventory. The Guidebook describes the methods employed to quantify Arizona's environmental flows and provides decision trees for those designing environmental flow studies. The WRRC is now working to improve understanding about ecological water needs and build upon continuing efforts to address increasing water demands around the state. Regionally focused materials developed from the AzEWNA work and other resources are being made available for water planning through a series of outreach presentations throughout the state. Our presentation at the Madrean Archipelago conference will highlight our findings on water needs of Arizona's environment and initial progress made with those involved in regional and state processes exploring what it means to consider the environment in water planning.

Evaluación de la situación ecológica de agua en Arizona. El Centro de Investigación de Recursos Hídricos (WRRC, por sus siglas en inglés) de la Universidad de Arizona tiene dos publicaciones técnicas de un proyecto de evaluación de la necesidad hídrica del medio ambiente en Arizona. El Informe y la Guía sobre las necesidades hídricas medioambientales de Arizona (AzEWNA por sus siglas en inglés) por primera vez exploran y sintetizan los trabajos para cuantificar las necesidades hídricas de los sistemas de ríos en Arizona. El Informe compila todo el conocimiento sobre las necesidades hídricas medioambientales, analiza las lagunas de información e incluye mapas y diagramas para ayudar a los lectores a visualizar el alcance del estudio. La Guía describe los métodos utilizados para cuantificar los flujos medioambientales de Arizona y contiene árboles de decisión para quienes estén diseñando estudios de los flujos medioambientales. El WRRC está trabajando para mejorar la comprensión de las necesidades ecológicas de agua y fortalecer el trabajo continuo para enfrentar la creciente demanda de agua en el estado. Materiales para la región elaborados en base a los resultados de AzEWNA y otros recursos se están proporcionando para la planificación del uso de agua por medio de presentaciones al público del estado. Esta presentación hará hincapié en nuestras conclusiones sobre las necesidades hídricas del medioambiente de Arizona y el progreso inicial logrado con quienes trabajan en los procesos regionales y estatales, y que tienen interés en considerar el medioambiente en la planificación hídrica.

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A decade of wildlife tracking in the Sky Islands. In 2001 Sky Island Alliance developed a citizen science program that uses track and sign identification and count surveys to monitor potential wildlife corridors throughout southeastern Arizona and southwestern New Mexico. The goal of the Wildlife Linkages Program is to protect and advocate for an interconnected landscape where wildlife, based on their ecological needs, can move easily between core habitats, the Sky Island mountain ranges. Currently, we train and engage volunteers in the monitoring of fifty 1.5 mile-long transects within seven priority linkage areas; the majority of these study areas are located on public lands. To date we have conducted over 1,000 track count surveys and documented over 4,100 records for more than 40 different animal species in the region. Sky Island Alliance has successfully applied the resulting species presence data to land-use policy and permanent land conservation, incorporating wildlife data and corridor priorities into the Sonoran Desert Conservation Plan, the Santa Cruz County Comprehensive Plan, the Pima County Wildlife Connectivity Assessment and the Arizona Wildlife Linkages Assessment.

Una década de rastreo de fauna en las Islas Serranas. En 2001 Sky Island Alliance desarrolló un programa que usa la identificación de huellas y marcas de animales y cuenta los transectos para monitorear corredores potenciales de fauna en el sureste de Arizona y suroeste de Nuevo México. La meta del Programa de Enlaces de Fauna Silvestre es proteger y abogar por un paisaje interconectado donde la fauna, con base en sus necesidades ecológicas, pueda moverse fácilmente entre sus hábitats principales, las cordilleras de las Islas Serranas. Actualmente, se capacita y trabaja con voluntarios en el monitoreo de cincuenta transectos de 2.5 kilómetros de longitud ubicados en siete áreas prioritarias; la mayoría en áreas naturales del gobierno. A la fecha hemos realizado más de 1,000 muestreos usando huellas y documentado más de 4,100 registros de más de 40 diferentes especies animales en la región. La información resultante sobre la presencia de especies y su análisis, ha sido aplicada exitosamente a políticas de uso de suelo y conservación permanente de tierras, incluyendo la incorporación de información sobre fauna y corredores prioritarios en el Plan de Conservación del Desierto Sonorense, el Plan Comprehensivo del Condado Santa Cruz, la Evaluación de Conectividad de Fauna del Condado Pima y la Evaluación de Enlaces para la Fauna Silvestre de Arizona.

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Ecological divergence of *Larrea tridentata* at the Chihuahuan-Sonoran Desert ecotone. The Chihuahuan and Sonoran Desert floras have evolved largely in isolation, separated by the Sierra Madre Occidental. Biogeographers have debated the location of the present-day boundary between these deserts, although Shreve, among others, suggested this transition occurred in the low elevation areas of the Gila and San Pedro river drainages of Arizona. Now desert scrub, this area is thought to have been grassland approximately 100 years ago. The dominant and widespread shrub creosote bush (*Larrea tridentata* (DC.) Coville; Zygophyllaceae) occurs throughout the warm deserts of North America, with three cytotypes that are broadly distributed in the Chihuahuan (diploid), the Sonoran (tetraploid and hexaploid), and the Mojave (hexaploid)

Deserts. Here, we describe an abrupt (~10 km) transition between diploid and tetraploid *L. tridentata* in the Gila and San Pedro River drainages. This cytotype transition, and predictions from ecological niche modeling, suggests a persistent ecotone between the Chihuahuan and Sonoran Deserts and raises interesting questions about the historical extent of these biogeographic provinces. Future efforts to obtain packrat (*Neotoma*) midden data from the low elevations of the eastern Catalina and northwestern Galiuro Mts. would be particularly informative for determining ancient botanical communities of the area and further elucidate the desert boundaries.

La divergencia de *Larrea tridentata* en el ecotono de los desiertos Chihuahuense y Sonorense. La flora de los desiertos Chihuahuense y Sonorense ha evolucionado en gran parte aislada, separada por la Sierra Madre Occidental. Los biogeógrafos han debatido la ubicación de la frontera actual entre estos desiertos, aunque Shreve, sugirió que esta transición ocurre en las zonas de baja altitud de los drenajes de los ríos Gila y San Pedro de Arizona. Esta área actualmente es matorral desértico, pero se cree que hace aproximadamente 100 años fue pastizal. La gobernadora (*Larrea tridentata* (DC.) Coville; Zygophyllaceae), común y con distribución amplia, ocurre en todos los desiertos cálidos de Norteamérica, con tres citotipos distribuidos extensamente en el Desierto Chihuahuense (diploide), el Desierto Sonorense (tetraploide y hexaploide) y el Desierto Mohave (hexaploide). Aquí describimos una transición abrupta (~10 km) entre *L. Tridentata* diploide y tetraploide en los drenajes del río Gila y río San Pedro. Esta transición de citotipo, y las predicciones de modelos de nichos ecológicos, sugiere que hay un ecotono persistente entre los desiertos Chihuahuense y Sonorense y hace pensar sobre el alcance histórico de estas provincias biogeográficas. Estudios futuros con datos de paleomadrigueras de roedores del género *Neotoma* de elevaciones bajas del este de la Sierra Catalina y del noroeste de la S. Galiuros serían especialmente informativos para identificar las comunidades botánicas antiguas de la zona y aclarar más las fronteras desérticas.

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Black Bear population and connectivity in the Sky Islands of Mexico/United States. The Sky Island region is a mountainous region surrounded by grasslands, deserts and intermountain valleys, located between Mexico and the United States. However, different land management and human impact can have an effect on its wildlife populations. Currently, the border wall poses an immediate threat to the survival of black bears (*Ursus americanus*), considered an endangered species in Mexico. Our aim was to determine the conservation status of black bear in the Sierra San Luis as affected by the border fence. We determined population size through camera trap and radio-telemetry, and modeled population occupancy using PRESENCE. We documented a bear population with more than 500 individuals. Surveys along the border failed to detect bears crossing it, but we identified linkages between the two countries important for future landscape planning. Increased vehicular traffic, migration and drug traffic have a negative effect on bear populations, exacerbated by an increase in anthropogenic activities resulting from the construction and maintenance of the border wall. We recommend modifications to the structure of the border wall, and to increase wildlife monitoring by the United States authorities to reduce the potential impact this structure has on black bear and other wildlife populations.

Población de oso negro y su conexión en las Islas Serranas de México y Estados Unidos. La región de las Islas Serranas es un área montañosa rodeada por pastizales, desiertos y valles ubicada en México y Estados Unidos. Sin embargo, un manejo e impacto humano diferente pueden afectar sus poblaciones de fauna. Actualmente, el muro fronterizo representa una amenaza inmediata para la supervivencia del oso negro (*Ursus americanus*), una especie en peligro en México. El objetivo de este trabajo fue determinar como el muro fronterizo afecta el estado de conservación del oso negro en la Sierra San Luis. Determinamos el tamaño de la población mediante cámaras trampa y radio-telemetría, y se hizo un modelo de población usando PRESENCE. Registramos una población de osos con más de 500 individuos. Monitoreos cerca de la línea fronteriza no detectaron osos cruzándola, pero identificamos corredores entre los dos países importantes para el manejo futuro del paisaje. Aumento del tráfico vehicular, migración humana y tráfico de drogas tienen un efecto negativo en las poblaciones de osos, empeorado por un aumento de actividades antropogénicas por la construcción y mantenimiento del muro. Recomendamos modificaciones a la valla, y un aumento del monitoreo de fauna por parte de Estados Unidos para reducir el posible impacto de esta estructura en las poblaciones de oso negro y otras especies de fauna.

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Mammalian diversity in the Sky Islands, Sonora, México. The sky island system of northwestern Mexico has been known as a center for biodiversity, nevertheless land tenure and management of populations may create alternative patterns of diversity. The objective of this study was to estimate the mammalian species richness and diversity of the sky islands of northeastern Sonora, Mexico. During 2009-2011, we used camera trapping (between 21 to 40 per location) at 13 sites, at mountain ranges and lower elevations. We determined species richness through species accumulation curves. We documented a total of 27 species, with a range of seven to 21 per site, finding significant differences between sampled areas. Jaccard's similarity index yield a variation between 32 to 95% among sites. Our results show a different composition of species, with relevant populations of endangered species such as black bears (*Ursus americanus*), and also important connectivity for species such as badger (*Taxidea taxus*), jaguar (*Panthera onca*), and ocelot (*Leopardus pardalis*).

La diversidad de mamíferos en las Islas Serranas de Sonora, México. El sistema de las Islas Serranas del noroeste de México se conoce como centro de biodiversidad, sin embargo la tenencia de tierras y el manejo de poblaciones puede resultar en patrones diferentes de diversidad. El objetivo de este estudio fue estimar la riqueza y diversidad de mamíferos de las Islas Serranas del noreste de Sonora, México. De 2009 a 2011, usamos cámaras trampa (de 21 a 40 por lugar) en 13 sitios, en cordilleras y altitudes más bajas. Determinamos riqueza de especies usando curvas de acumulación. Registramos 27 especies, variando de 7 a 21 por sitio, con diferencia significativa entre áreas. El índice de similitud de Jaccard da una variación entre 32 y 95% entre los sitios. Nuestros resultados muestran una composición variada de especies, con poblaciones relevantes de especies en peligro como el oso negro (*Ursus americanus*), y también conectividad importante para especies como tejones (*Taxidea taxus*), jaguar (*Panthera onca*) y tigrillo (*Leopardus pardalis*).

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Perceptions about climate change influence support for forest adaptation measures. Land managers can draw from a toolbox of potential management responses in an effort to adapt to climate change and mitigate some of its impacts. In order to consider the level of acceptance for various adaptation responses among land managers and scientists, we administered a detailed anonymous survey. It was distributed at a May 2011 National Workshop on Climate and Forests held in Flagstaff, Arizona, and electronically by the Society of American Foresters and the Association of Natural Resource Extension Professionals. Results compiled from the 1,029 U.S.-based respondents will be described. The research was designed to consider whether participants' perceptions about climate change influenced their perceived acceptance of various climate and proxy records and their willingness to consider different forest adaptation and mitigation management techniques. Another research goal was to foster a greater understanding of how researchers and educators can better provide for the needs of forest managers. The results also provide an indication of the acceptability of specific management techniques to the group as a whole and by specific sector. Results will be considered for the nation as a whole and, using a subset of respondents who provided geographic information, for the Southwest specifically.

Percepciones sobre el cambio climático influyen el respaldo a medidas de adaptación forestal. El personal de manejo de recursos puede escoger entre posibles formas de manejo con el fin de adaptarse al cambio climático y mitigar algunos de sus impactos. Para considerar el nivel de aceptación de varios métodos de adaptación entre personal de manejo y científicos, aplicamos un cuestionario anónimo. Se distribuyó en el Taller Nacional de Clima y Bosques en Flagstaff, Arizona en mayo de 2011, y electrónicamente por la Sociedad de Silvicultores Americanos y la Asociación de Profesionales de Extensión de los Recursos Naturales. Los resultados recopilados de 1,029 encuestados en E.U. se describirán a continuación. La investigación se diseñó para considerar si las percepciones de los participantes sobre el cambio climático influyeron su aceptación de varios registros y estimaciones climáticas y su disposición para considerar técnicas diferentes de adaptación forestal y de manejo de la mitigación. Otra meta de la investigación fue entender mejor cómo los investigadores y educadores pueden apoyar al personal de manejo forestal. Los resultados también indican la aceptación de técnicas de manejo específicas por todo el grupo y por sectores específicos. Los resultados se considerarán para la nación en conjunto y usando los cuestionarios que incluyen información geográfica, para el Suroeste, específicamente.

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A classification of intermittent and ephemeral streams on Department of Defense land. Ephemeral and intermittent streams are the predominant fluvial forms in arid and semiarid environments. Various studies have shown biodiversity and habitat values in these lands to be considerably higher along ephemeral and intermittent stream corridors in comparison to adjacent uplands. Yet, knowledge of how hydrologic properties of these systems are linked to their ecological function is limited, leading to difficulty in making well-informed management decisions. To improve decision making, this research will develop an ecohydrologically-based classification scheme that distinguishes ephemeral and intermittent channel types by a set of biotic and abiotic attributes that are directly related to their hydrologic regime. Using the stream type classification, we will develop an assessment methodology that allows Department of Defense managers to evaluate the impacts of perturbations (e.g., climate change, military activities) on the hydrologic regimes of these systems and the species that depend on them. Methods include analysis of GIS and high-resolution remote sensing data, and hydrologic modeling (AGWA/KINEROS/SWAT). Statistical approaches such as classification and regression trees will be used to classify ephemeral and intermittent streams along a xeric to mesic gradient.

Una clasificación de arroyos intermitentes y efímeros en las tierras del Departamento de Defensa. Los arroyos intermitentes y efímeros son las formas fluviales predominantes en los ambientes áridos y semiáridos. Varios estudios han mostrado que los valores de la biodiversidad y el hábitat en estas tierras son considerablemente más altas en los corredores de los arroyos efímeros e intermitentes comparados con las tierras altas colindantes. Pero el conocimiento de cómo las propiedades hidrológicas de estos sistemas están vinculadas a sus funciones ecológicas es limitado, haciendo difícil que se tomen decisiones de manejo bien informadas. Para mejorar la toma de decisiones, esta investigación desarrollará una clasificación ecohidrológica que identifica las corrientes intermitentes y efímeras por un grupo de atributos bióticos y abióticos directamente relacionados al sistema hidrológico. Utilizando la clasificación de tipo de arroyo, desarrollaremos una metodología de evaluación para que los administradores del Departamento de Defensa puedan evaluar los impactos de las perturbaciones (ej. cambio climático, actividades militares) en los regímenes hidrológicos de estos sistemas y las especies que dependen en ellos. Los métodos incluyen análisis de datos de SIG, sensores remotos de alta resolución y modelos hidrológicos (AGWA/KINEROS/SWAT). Métodos estadísticos como diagramas de regresión y clasificación se utilizarán para identificar los arroyos intermitentes y efímeros en un gradiente de árido a méxico.

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Ecologic aspects related with the potential of species of the Sonoran Desert for the use of biofuels. The use of biofuels is proposed for an alternative to decrease the negative effects related with the climatic change for the use of fossil fuels. In arid lands there are a great proportion of species that produce important quantities of oil in the seeds. In this study we determine the content and composition of oils (fatty acids) of different families of arid land plants in Mexico. We did determinations in the laboratory with gas chromatography and bibliographic values to their potential as a possible source for biofuels. The ease of combustion of a biofuel is determined by the cetane number, which is related to the proportion of unsaturated and saturated fatty acids. The proportion of unsaturation of fatty acids is related to the environmental conditions of place of origin of the species, which is higher in colder places. We found lower cetane numbers for a high proportion of unsaturated fatty acids in the Brassicaceae family, followed by species in the families Asteraceae, Cucurbitaceae, Euphorbiaceae, Oleaceae, Malvaceae, and Fabaceae. This reflects the capacity of the family Brassicaceae for growth in habitats colder than other families and the origin more tropical of Fabaceae. This study propose a greater analysis of the content and composition of fatty acids in species of arid lands for the determination of the potential of possible source of biofuels.

Aspectos ecológicos relacionados con el potencial de especies del Desierto Sonorense para su uso como biocombustibles. El empleo de biocombustibles ha sido propuesto como alternativa a la disminución y los efectos negativos relacionados con el cambio climático derivados de los combustibles fósiles. En zonas áridas existe una gran proporción de especies que producen cantidades importantes de aceites en sus semillas. En este estudio se determinaron los contenidos y composición de aceites (ácidos grasos) de diversas familias de plantas de las zonas áridas de México. Tanto determinaciones en el laboratorio por cromatografía de gases como valores obtenidos de la bibliografía mostraron un potencial de fuentes posibles para uso como biocombustible. La facilidad con que un biocombustible efectúa su combustión esta determinada con su número de cetano, el cual se ha relacionado a su vez con la proporción de ácidos grasos insaturados y saturados. La proporción de insaturación de los ácidos grasos se ha encontrado estar relacionada con las condiciones ambientales de los lugares de origen de las especies, siendo mayor esta proporción en lugares más fríos. Se encontró un menor número de cetano debido a una mayor proporción de ácidos grasos insaturados en la familia Brassicaceae, seguido de especies en las familias Asteraceae, Cucurbitaceae, Euphorbiaceae, Oleaceae, Malvaceae y Fabaceae. Lo anterior refleja también la capacidad de la familia Brassicaceae para crecer en habitats mas templados que las otras familias y el origen más tropical de Fabaceae. El estudio propone un mayor análisis del contenido y composición de ácidos grasos en especies de zonas áridas para determinar su potencial como fuentes posibles de biocombustibles.

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An unprecedented mountain pine beetle outbreak in the Pinaleno Mountains. Mountain pine beetle (MPB, *Dendroctonus ponderosae* Hopkins) has incurred an unprecedented outbreak in the Pinaleno Mountains of southeast Arizona. MPB has rarely been observed in southern Arizona, is not recorded from the Pinalenos, and has no record as a significant damage agent south of Flagstaff. In recent years, though, it has been killing southwestern white pine (SWWP, *Pinus strobiformis*) and occasional ponderosa pine (*P. ponderosa*) in small patches in the Pinalenos. Mortality each year is minor, but the outbreak has persisted for at least 12 years and cumulative effects have reached ecologically significant levels that affect resource values. We sampled MPB-infested plots and compared them to a random sample of SWWP-inhabiting plots. Average stocking and SWWP dominance on infested plots were each approximately twice what was found in the random sample. Trees as small as 13 cm dbh were attacked. Cross dating the attack years of killed trees indicates that the outbreak has persisted at least 12 years. MPB population dynamics are temperature-responsive, and in this situation the life cycle appears to be univoltine. The ultimate course of the outbreak is unknown, but is likely to significantly affect the character of the Pinaleno mixed-conifer forest.

Una plaga sin precedentes del descortezador de pinos en la Sierra Pinaleno. El descortezador (*Dendroctonus ponderosae*) ha provocado una plaga sin precedentes en la Sierra Pinaleno del sureste de Arizona. El descortezador rara vez se ha observado en el sur de Arizona, no se ha registrado en Pinalenos y no tiene antecedentes de ser un agente de daño significativo al sur de Flagstaff. Pero en años recientes ha matado el pino blanco del suroeste (*Pinus strobiformis*) y ocasionalmente pino ponderosa (*P. ponderosa*) en zonas pequeñas en Pinalenos. La mortalidad cada año es menor, pero la plaga ha persistido por lo menos 12 años y los efectos acumulativos han llegado a niveles ecológicamente significativos que afectan los recursos. Se hicieron muestreos en parcelas infestadas por descortezadores y se compararon con una muestra aleatoria de parcelas con pino blanco. Tanto el promedio del arbolado como la dominancia de pino blanco en las parcelas infestadas fueron casi el doble de la muestra aleatoria. Incluso árboles de 13 cm DBH fueron infestados. Al determinar los años de ataques de árboles muertos se concluye que la plaga ha persistido por lo menos 12 años. La dinámica de la población del descortezador es sensible a la temperatura, y en esta situación el ciclo de vida parece ser univoltino. Se desconoce como terminará esta plaga, pero es probable que afectará significativamente el bosque mixto de coníferas de los Pinalenos.

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Insects as agents of change: Contemporary forest insect outbreaks in the Arizonan Sky Islands. Predicted responses of forest insect populations to warming climate include altered distribution of key species, especially movement to higher elevation and higher latitudes; acceleration of herbivory rates; altered frequency and intensity of outbreaks; emergence of previously innocuous insects as pests; unpredictable interactions with natural enemy populations (parasites, predators, pathogens); and invasion of new habitats. Many of the predicted responses have already commenced in the Sky Islands. Recent forest insect activity in the Sky Islands has been remarkable for the multitude of insect species incurring outbreaks, the severity of damage, the appearance of new species as pests, and the temperature-sensitive population dynamics of several species. Nine species have experienced severe or unprecedented outbreaks in the last 20 years. Other damaging insects and pathogens have been active as well, especially after fire events and during drought years. Activity by so many species in such a short period of time in high elevation Sky Island forests indicates that insect populations in low-latitude high-elevation forests may be particularly responsive to climate change. Though the precise timing and nature of altered insect outbreak regimes is not predictable, it is certain that insects will play a major role in future change in the Madrean Sky Island forest ecosystems.

Los insectos como agentes de cambio: Brotes de plagas de insectos forestales en las Islas Serranas de Arizona. Las respuestas previstas de poblaciones de insectos forestales al calentamiento climático incluyen alteración en la distribución de especies claves, especialmente movimiento a elevaciones y latitudes más altas, incremento del índice de herbívoros, alteración de la frecuencia e intensidad de brotes, surgimiento de insectos inofensivos como plagas, interacciones imprevisibles con poblaciones enemigas naturales (parásitos, predadores, patógenos), y la invasión de nuevos hábitats. Muchas de las reacciones predichas ya han comenzado en las Islas Serranas. La actividad reciente de los insectos forestales en las Islas Serranas ha sido notable por la multitud de insectos plaga, la severidad del daño, el surgimiento de nuevas especies como plagas, y la dinámica de la población sensible a la temperatura en algunas especies. Nueve especies han experimentado brotes severos o sin precedentes en los últimos 20 años. Otros insectos y patógenos dañinos han estado activos también, especialmente después de incendios y en años con sequía. La actividad de tantas especies en tan corto tiempo en bosques de elevaciones altas de las Islas Serranas indica que las poblaciones de insectos en bosques de latitud baja y elevación alta podrían ser más sensibles al cambio climático. Aunque el momento y condiciones específicos de ataques de plagas no es predecible es seguro que los insectos tendrán un papel importante en los cambios futuros de los ecosistemas forestales de las Islas Serranas Madrenses.

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Floods, droughts, and aquatic biodiversity in the Madrean archipelago. The Madrean Sky Island region harbors a rich variety of aquatic habitats, ranging from mountain streams to lowland rivers and ciénegas. Compared with other regions, MSI aquatic habitats are unusual because they are patchily distributed across the landscape and strongly influenced by seasonal flooding and drought. This fragmented spatial arrangement coupled with strong disturbance dynamics has shaped both the evolution and ecology of MSI aquatic organisms. Many aquatic insects, fish, and riparian plants are now known to possess adaptations for surviving extreme events such as flash flooding or prolonged drought. Additionally, population genetic studies have revealed marked evolutionary divergence of aquatic populations at fine spatial scales. In one case, populations of an aquatic invertebrate predator have evolved unique behaviors to escape flash floods, and these behavioral adaptations differ in response to local canyon-scale flood regimes. Disturbance dynamics and spatial isolation also facilitate high aquatic invertebrate biodiversity within a surprisingly small amount of habitat, with largely distinct communities coexisting within meters of each other. This fine-scale partitioning of genetic and species diversity is a double edged sword. Although changes in hydrologic regime due to climate change, groundwater pumping and other factors have eliminated unique populations and communities, the diversity and adaptability of these organisms could provide resilience to ecological change.

Inundaciones, sequías, y biodiversidad acuática en el Archipiélago Madreño. La región de las Islas Serranas Madrenses alberga una gran variedad de hábitats acuáticos, desde los arroyos de montañas a los ríos y ciénegas de la tierra baja. Comparados con otras regiones, los hábitats acuáticos de la región Madreña son diferentes por estar fragmentados y bastante influenciados por inundaciones y sequías de estación. Esta fragmentación espacial combinada con fuertes dinámicas de disturbio ha influenciado la evolución y ecología de los organismos acuáticos de la región Madreña. Ahora se sabe que muchos insectos acuáticos, peces y plantas ribereñas están adaptados para sobrevivir eventos extremos, como son las crecidas o sequías prolongadas. Además, estudios genéticos poblacionales han revelado una marcada divergencia evolutiva de las poblaciones acuáticas en escalas espaciales pequeñas. En un caso, las poblaciones de un depredador invertebrado acuático han evolucionado comportamientos únicos para escapar de las crecidas, y estas adaptaciones conductuales difieren en respuesta a los regímenes locales de inundaciones a escala del cañón. Las dinámicas de perturbación y aislamiento espacial también facilitan una alta biodiversidad de invertebrados acuáticos en un hábitat sorpresivamente pequeño, con comunidades muy distintas coexistiendo separadas por unos cuantos metros. Esta división en una escala pequeña de diversidad genética y de especies es una espada de doble filo. Aunque los cambios en el régimen hidrológico debido al cambio climático, extracción de agua subterránea y otros factores han eliminado poblaciones y comunidades únicas, la diversidad y adaptabilidad de estos organismos podría aumentar la capacidad de recuperación del cambio ecológico.

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Analyzing changes in the spatial distribution of saguaros (*Carnegiea gigantea*) in Saguaro National Park. Results of the 2010 Saguaro Census at Saguaro National Park were used to analyze changes in spatial distribution of the saguaro cactus both within plots and park-wide. This was done by quantitatively comparing 11 historic 1-ha saguaro plots where individual saguaros were mapped in 1975 (by hand) and again in 2010 (by GPS) with 45 standard 2-ha census plots. Recently collected LiDAR data and aerial imagery were used in conjunction with the data from the saguaro census plots and additional high-elevation plots to evaluate elevation limitations of the existing population and create a suitable habitat model. The derived saguaro habitat was then also projected 50 years into the future using predicted growth rates and climatic factors to examine potential distribution of the species in the park. Results indicate a wide variety of expected changes in saguaro distribution related to age class structure, landscape, presence of external influences, and overall population dynamics.

Análisis de cambios en la distribución espacial de sahuaros (*Carnegiea gigantea*) del área protegida Saguaro National Park. El censo de sahuaros de 2010 de Saguaro National Park se usó para analizar cambios en la distribución espacial de sahuaros tanto en parcelas de muestreo como en todo el parque. Se compararon cuantitativamente 11 parcelas antiguas de 1 ha donde cada sahuaro se ubicó en un mapa en 1975 (a mano) y de nuevo en 2010 (con GPS) en 45 parcelas de censo estándares de 2 ha. Se usaron datos recientes de LiDAR, fotografías aéreas, datos del censo de sahuaros, y se incluyeron parcelas de elevaciones altas para evaluar las limitantes de elevación de la población existente y crear un modelo del hábitat adecuado. El hábitat de sahuaro obtenido se extrapólo 50 años en el futuro usando tasas de crecimiento y factores climáticos para examinar la distribución potencial de la especie en el parque. Los resultados indican una amplia variedad de cambios probables en la distribución de sahuaro relacionado con distribución por edad, paisaje, presencia de factores externos y dinámica de la población en general.

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Vegetation and flora of the St. David Ciénega. In this talk I will explore the St. David and Lewis Springs Ciénegas along the San Pedro River in Cochise County, Arizona – with an emphasis on the flora. In the Sky Island region, ciénegas are rare marshlands amidst arid surroundings where groundwater perennially intersects the surface. Because of their unique soil and hydrological properties, ciénegas maintain a trajectory toward graminoid wetlands. Evaporation usually causes the water to be alkaline, and vegetation around a ciénega commonly includes halophytes and other unusual species. Depending on their age and size, they may also harbor high levels of endemism. Ciénegas are far from pristine, and like many wetlands and riparian areas, they have probably been exploited for millennia. However, in the American Southwest, these habitats are hypothesized to have been in severe decline over the past 150 years due to a cycle of erosion and arroyo cutting. In light of their biological and cultural importance, it is important to learn as much as we can about their current condition and conservation potential.

Vegetación y flora de la Ciénega de San David. En este trabajo presentaré la ciénega de San David y el aguaje Lewis del río San Pedro en el condado de Cochise, Arizona – con énfasis en la flora. En la región de las Islas Serranas, las ciénegas son humedales escasos en ambientes áridos donde el agua subterránea sube a la superficie de forma constante. Debido a su suelo y propiedades hidrológicas únicas, las ciénegas mantienen un humedal graminoide. La evaporación usualmente causa que el agua sea alcalina, y la vegetación de la ciénega frecuentemente incluye halófitas y otras especies inusuales. Y dependiendo de su edad y tamaño, también pueden albergar niveles altos de endemismo. Las ciénegas distan mucho de ser prístinas, e igual que muchos humedales y zonas ribereñas, probablemente se han explotado por milenios. Sin embargo, en el Suroeste Norteamericano, se asume que estos hábitats han estado en declive severo los últimos 150 años debido a un ciclo de erosión y fragmentación por arroyos. Debido a su importancia biológica y cultural, es importante estudiar todo lo posible sobre su condición actual y potencial de conservación.

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Mapping vegetation and landscapes utilizing a multiple-scale approach in southeastern Arizona. To advance a Forest Service standard for ecosystem mapping at multiple scales, the USFS in 2010 issued a directive mandating the use of “The National Hierarchical Framework of Ecological Units.” (Cleland et al.1997). Fortunately the Coronado NF and other agency partners had been moving in this direction since 2007, when they supported a pilot project to map its lands at landscape scales, resulting in a first approximation of Landtype Associations (LTAs) of southeastern Arizona. Criteria used in mapping LTA’s include bedrock and superficial geology, topography, elevation, potential and existing vegetation, key soil properties, and local climatic variables. The mapping effort has benefited the Coronado’s FireScape program, in which multiple partners utilize this mapping as a framework for fire planning. Second generation LTA maps for the Catalina-Rincon mountains, which are available at www.azfirescape.org, are used for managing ecological units (e.g., mixed conifer on granitic soils) typically no smaller than a thousand acres, and often much larger. Not surprisingly, the success of the project depends on an accurate depiction of vegetative and physical setting reality, not just interpretations of remote imagery. To that end, FireScape supports extensive on-the-ground data collection, often with surprising revelations about places we assumed we already knew.

Trazado de mapas de vegetación y paisaje utilizando una escala múltiple en el sureste de Arizona. Para mejorar el método del Servicio Forestal para trazar mapas de ecosistemas con escalas múltiples, en 2010 el Servicio Forestal emitió una circular exigiendo el uso del “Marco Nacional Jerárquico de Unidades Ecológicas.” (Cleland et al. 1997). Afortunadamente el Bosque Nacional Coronado y colaboradores ya habían empezado desde 2007, cuando apoyaron un proyecto piloto para trazar mapas de sus montes a escala del paisaje, resultando en una primera

aproximación de Asociaciones de los Tipos de Tierras (ATT) del sureste de Arizona. Los criterios usados en el trazado de mapas ATT incluyen: lecho rocoso y geología, topografía, altitud, vegetación actual y potencial, tipo de suelo y datos meteorológicos locales. Estos mapas son usados en el programa FireScape del Bosque Nacional Coronado y los socios utilizan estos mapas como referencia para programar incendios. La segunda edición de mapas ATT de la Sierra Catalinas y S. Rincón, (disponibles en www.azfirescape.org) se usan para el manejo de unidades ecológicas (e.g., bosques mixtos de coníferas en suelos de granito) de 400 has o más grandes. Como es de esperarse el éxito del proyecto depende de una representación exacta del entorno vegetal y físico, no solamente de las imágenes de satélite. Con este objetivo, FireScape apoya la toma de datos de campo exhaustiva, frecuentemente con descubrimientos sorprendentes sobre lugares supuestamente conocidos.

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Potential for extending major resource areas into northern Mexico. There is a significant history of cooperative efforts between Mexico and the United States on natural resource management issues including rangeland management. Mexico and the U.S. have jointly conducted research and developed range management technologies. Bringing these technologies together and improving technical communications are an ongoing process. This paper discusses a potential tool that can provide a common denominator for both countries to more easily frame, describe, and share data relative to rangeland resources. The objective is to present possibilities for utilizing current data and provide a vehicle that can facilitate technical communications. Existing maps including climate and elevation were used to define probable areas of Chihuahua and Sonora that would be similar enough to Major Land Resource Areas (MLRAs) of Arizona to consider them an extension of those MLRAs. Reconnaissance surveys were made to compare soils and vegetation to those described in Arizona. Comparisons were also made between Ecological Site Descriptions (ESDs) used in the U.S. with those developed in Mexico by COTECOCA. A preliminary map was developed that represents probable boundaries of MLRA 41 if extended from the U.S. border into the states of Chihuahua and Sonora. Some sites were mapped to test application of U.S. ecological site descriptions with on ground conditions in Chihuahua. The potential for extending MLRA boundaries from the U.S. into Mexico is feasible and realistic. This would facilitate the direct use of Ecological Site Descriptions across borders and improve exchange of rangeland data between the two countries.

Potencial de extender las áreas claves de recursos en el norte de México. México y Estados Unidos comparten una historia de colaboración en temas del manejo de recursos naturales, incluyendo el manejo de agostaderos. México y E.U. han realizado investigaciones y desarrollado tecnologías para el manejo de agostaderos conjuntamente. Unir estas tecnologías y mejorar la comunicación técnica son procesos en desarrollo. Este artículo presenta una herramienta potencial que puede proveer un punto en común para que ambos países puedan formular, describir y compartir datos en relación con los recursos del agostadero más fácilmente. El objetivo es presentar las posibilidades de utilizar los datos actuales y proveer un vehículo que pueda facilitar las comunicaciones técnicas. Los mapas existentes que incluyen el clima y la elevación se usaron para definir zonas de Chihuahua y Sonora que probablemente serían muy similares a las Áreas Claves de Recursos Terrestres (ACRT) de Arizona para considerarlas una extensión de tales ACRT. Se hicieron inspecciones terrestres para comparar suelo y vegetación con los descritos en Arizona. También se hicieron comparaciones entre las Descripciones de los Sitios Ecológicos (DSE) usados en E.U. con los desarrollados en México por COTECOCA. Se desarrolló un mapa preliminar que representa los límites probables de ACRT 41 si se extendieran de la frontera E.U. a los estados de Sonora y Chihuahua. Algunos sitios se trazaron en una mapa para probar la aplicación de las descripciones de los sitios ecológicos estadounidenses con las condiciones sobre el terreno en Chihuahua. El potencial de extender los límites de los ACRT de los E.U. a México es realizable y realista. Esto facilitaría el uso directo de los Descripciones de los Sitios Ecológicos a través de la frontera y mejoraría el intercambio de datos del agostadero entre los dos países.

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Energy by Design: A tool for achieving no net conservation loss with transmission line and power plant siting. The Madrean region has recently been the focus of several large energy-related development proposals, including power generating plants and long-distance electrical transmission lines. The implementation of such projects could have significant and widespread conservation impacts, and yet environmental considerations are often only considered late in the regulatory process when the cost of reconciling tradeoffs is high. We present an approach called Energy by Design that was developed to minimize the impacts of energy infrastructure by integrating the best available science early into regulatory and planning processes. The premise of the energy by design framework is to make tradeoffs explicit and identify a range of options that would help achieve a standard of no net loss of conservation values. The standard is met through use of the mitigation hierarchy where options are identified to avoid, minimize, restore, and offset major project impacts to habitat and species at large landscape and local scales. We will use the SunZia Southwest Transmission Project in Southeastern Arizona as an example of the application of Energy by Design principles.

Energía por Diseño: Cero pérdida de la conservación con el emplazamiento del cableado y plantas generadoras. La región Madrean recientemente ha sido el foco de varias propuestas de desarrollo relacionadas con la energía, incluyendo las plantas generadoras de electricidad y cableados de larga distancia. La implementación de tales proyectos podría tener impactos considerables y extensos en la conservación, aún así las consideraciones medioambientales frecuentemente sólo se consideran tarde en el proceso normativo cuando el costo de reconciliar los compromisos es alto. Presentamos el enfoque Energía por Diseño que se desarrolló para minimizar los impactos de la infraestructura al integrar la mejor ciencia disponible a los procesos normativos y de planificación. La premisa del marco de la Energía por Diseño es hacer explícitos

los compromisos e identificar una gama de opciones que ayudarían a lograr un estándar de cero pérdida neta de los valores de conservación. El estándar se alcanza por el uso de la jerarquía de mitigación en la cual las opciones se identifican para evitar, minimizar, restablecer y compensar los impactos importantes al hábitat y las especies en escalas grandes de paisaje y locales. Utilizaremos el Proyecto de Transmisión Suroeste SunZia en el sureste de Arizona como ejemplo de la aplicación de los principios de Energía por Diseño.

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Impacts of effluent subsidies on riparian resilience. In 2005, a significant and sudden vegetation die-off event occurred in the riparian corridor of the Upper Santa Cruz River in southern Arizona. Analysis of past and current vegetation along the river suggests that this event can be linked to two competing factors relating to the discharge of treated municipal effluent into the river. Examination of records of riparian vegetation indicates an increase in the extent and density of vegetation in the 1980s and 1990s; this increase coincided with the presence of effluent subsidies and favorable climate conditions that encouraged growth. However, while water quantities in the river supported vigorous vegetative growth, poor effluent water quality was slowly hindering hydrologic functions. Our analysis of the riparian ecosystem suggests that the 2005 event was partially due to the eventual extreme degradation of the river's hydrologic functions coupled with drought conditions of the 2000s. The die-off, along with the results of our analysis, highlight the uncertainties and unknowns of effluent use in the Upper Santa Cruz River and further highlight the need to develop scientific and legal mechanisms to ensure that effluent bolsters, rather than degrades, riparian function and the provision of riparian ecosystem services in the semi-arid southwestern United States.

Impactos de aguas residuales en la resiliencia de hábitats ribereños. Una mortandad generalizada de plantas ocurrió en 2005 en el corredor ribereño del alto río Santa Cruz en el sureste de Arizona. Análisis de la vegetación histórica y actual del río sugiere que este evento puede vincularse a dos factores relacionados con descarga de aguas residuales municipales tratadas al río. Los registros de vegetación ribereña indican un aumento de la extensión y densidad de la vegetación en la década de 1980 y 1990, este aumento coincidió con la presencia de descarga de aguas residuales y un clima favorable que fomentaron el crecimiento. Sin embargo, mientras las cantidades de agua en el río ayudaron al crecimiento vegetal vigoroso, la mala calidad de aguas residuales gradualmente entorpeció las funciones hidrológicas. Nuestro análisis del ecosistema ribereño sugiere que la mortandad de 2005 se debió en parte a la degradación extrema de las funciones hidrológicas del río, aunado a las condiciones de sequía de la década de 2000. La mortandad, junto con los resultados de nuestro análisis, resalta las incertidumbres y las incógnitas del uso de aguas residuales en el alto río Santa Cruz y enfatiza la necesidad de desarrollar mecanismos científicos y legales para asegurar que se refuerce, en vez de degradar, el funcionamiento ribereño y suministro de los servicios ecológicos ribereños en el suroeste semiárido de Estados Unidos.

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Into the third dimension: Benefits of incorporating LiDAR data in wildlife habitat models. LiDAR (Light detection and ranging) is an increasingly useful tool for characterizing wildlife habitat, providing detailed, three-dimensional landscape information not available from other remote sensing applications. The ability to accurately map structural components such as canopy height, cover, woody debris, tree density, and ground surface can greatly improve wildlife habitat models as animals interact and respond to three-dimensional habitat features. Prior to LiDAR, accurate measurements of structural features were difficult to obtain over large areas and other remotely sensed data is based on two-dimensional spectral responses. The southwest harbors an incredible diversity of unique vegetation communities, each with an associated wildlife assemblage with various management needs. LiDAR is a unique tool, managers can use to accurately characterize vegetation structural characteristics for entire districts or management units. Data surfaces derived from the LiDAR point cloud can be readily incorporated into species-specific or multispecies habitat models. Although LiDAR has received much attention in characterizing forest structure, few studies (n = 28) have suggested or incorporated this technology to improve wildlife habitat models. Herein we provide a review of current LiDAR applications in wildlife habitat models, provide future directions, and detail how LiDAR can increase our ability to represent the world's animal experience.

A la tercera dimensión: Beneficios de incorporar los datos de LiDAR en los modelos del hábitat de fauna. El LiDAR (Light Detection and Ranging; detección y medición a través de la luz) es una herramienta cada vez más útil para evaluar el hábitat de fauna, aportando información tridimensional detallada que no se puede obtener con otros sistemas de detección remota. La capacidad de trazar en mapas con exactitud los componentes estructurales como la altura del dosel, la cobertura, el detrito leñoso, la densidad arbórea y la superficie del suelo pueden mejorar los modelos de hábitat ya que los animales interactúan y responden a las características tridimensionales del hábitat. Antes del LiDAR, las mediciones exactas de las características estructurales eran difíciles de obtener en áreas grandes y otros datos de sensores remotos se basan en las respuestas espectrales bidimensionales. El suroeste norteamericano alberga una diversidad increíble de comunidades vegetales únicas, cada uno con ensambles de fauna asociada con varias necesidades de manejo. El LiDAR es una herramienta que los encargados de manejo pueden usar para evaluar con exactitud las características estructurales de la vegetación por regiones completas o unidades de manejo. Los datos derivados de LiDAR pueden incorporarse fácilmente a modelos de hábitat para una o varias especies. Aunque el LiDAR se conoce como una herramienta para definir la estructura forestal, pocos estudios (n = 28) han utilizado esta tecnología para mejorar los modelos del hábitat de fauna. Se presenta una síntesis de las aplicaciones actuales del LiDAR en modelos de hábitat faunísticos, señalamos futuros usos y cómo el LiDAR puede aumentar nuestra capacidad de representar la experiencia del mundo animal.

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Do plant biomes along the elevation gradient in the Santa Catalina Mountains harbor unique arthropod communities? The southwestern sky islands represent one of the most diverse regions in North America for arthropods. However, land managers are ill equipped to make informed decisions concerning the preservation of arthropods or predict how arthropods will respond to climate change because fundamental questions about species distributions and diversity remain unanswered. The lack of data for most arthropod groups means that management decisions are often based on extrapolations from the few taxa studied, despite it being unclear if such patterns can be generalized across taxa. To address these shortcomings we are examining whether patterns of community structure and diversity among seven evolutionarily distinct ground-dwelling arthropod groups (ants, beetles, soil mites, grasshoppers, millipedes, isopods, scorpions/ pseudoscorpions) covary in the Santa Catalina Mountains. Collections were made using pitfall traps at 66 sites that, taken together, span the elevational gradient of the Catalinas, ranging from desertscrub, chaparral, and grasslands at low elevations to oak, pine, and mixed conifer forests at higher elevations. Preliminary data on ant and beetle assemblages indicate that different plant biomes harbor unique communities. In addition to providing valuable baseline data, this study will help identify vulnerable high elevation arthropod species that could be “pushed off” the mountaintop as climates warm.

Los biomas vegetales del gradiente altitudinal de la Sierra Santa Catalina, ¿albergan comunidades únicas de artrópodos? Las Islas Serranas del suroeste norteamericano representan una de las regiones con fauna de artrópodos más diversas de Norteamérica. Sin embargo, los encargados de manejo no están preparados para hacer decisiones acerca de la conservación de artrópodos o predecir cómo responderán al cambio climático ya que su distribución y diversidad se desconocen. La falta de datos para la mayoría de los grupos de artrópodos significa que las decisiones administrativas frecuentemente se basan en la extrapolación de los pocos taxones estudiados, aunque se desconoce si tales patrones se pueden generalizar entre taxones. Para encontrar una solución estamos investigando si los patrones de estructura y diversidad de la comunidad, entre siete grupos evolutivamente distintos de artrópodos epiedálicos (hormigas, escarabajos, ácaros del suelo, chapulines, miriápodos, isópodos, alacranes /seudo-alacranes) presentan covarianza en la Sierra Santa Catalina. Las colectas se hicieron usando trampas de caída en 66 sitios a lo largo de un gradiente altitudinal en las Catalinas, cubriendo desde matorral desértico, chaparral y pastizal en las elevaciones bajas, hasta los bosques de encino, pino, y coníferas mixtas en elevaciones altas. Los datos preliminares de los ensambles de hormigas y escarabajos indican que los diferentes biomas vegetales albergan comunidades únicas. Además de aportar datos de referencia valiosos, este estudio servirá para identificar las especies de artrópodos vulnerables en elevaciones altas que podrían ser “empujadas” de las cumbres cuando el clima se caliente.

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Population structure and the landscape genetics of a common desert anuran. Desert streams play a prominent role in shaping hydrological, biogeochemical, and ecological structure of arid and semi-arid ecosystems. Many anurans in the Madrean Archipelago rely on streamflows generated by winter storms and summer monsoons that provide favorable breeding habitat and hydrologic connectivity with individuals or populations that are otherwise isolated by harsh and dry habitat. The predictability, frequency, and magnitude of these flows will likely be altered by climate change and increasing human requirements for freshwater. Examining population structure of desert anurans - and its relationship to hydrology - is an important step in understanding how these species will be affected by climate change and land use. We present results of a landscape genetic analysis of one common desert anuran of the Madrean Archipelago, *Spea multiplicata* (Mexican spadefoot). Individuals were collected during the summers of 2010 and 2011. We first examine population structure throughout the Huachuca, Santa Rita, and Dragoon Mountain ranges. We then examine the relationship of population structure to major landscape features, including hydrology. These results are the first part of a comparative study examining the role of hydrology in population structure of multiple anuran species found throughout the Sky Islands.

Estructura de población y genética del paisaje de un anuro desértico común. Los arroyos del desierto tienen un papel fundamental en la estructura hidrológica, biogeoquímica y ecológica de los ecosistemas áridos y semiáridos. Muchos anuros del Archipiélago Madreño dependen de caudales generados por las tormentas invernales y el monzón del verano que generan hábitat favorable para la reproducción y la conectividad hidrológica con individuos o poblaciones, de otra forma aislados por un entorno hostil y seco. La predecibilidad, frecuencia y magnitud de estas corrientes probablemente serán alteradas por el cambio climático y el aumento del requisito humano de agua dulce. Investigar la estructura de la población de los anuros desérticos, y su relación a la hidrología, es un paso importante para entender cómo estas especies serán afectadas por el cambio climático y el uso del suelo. Presentamos el análisis de la genética de paisaje de un anuro desértico común del Archipiélago Madreño, *Spea multiplicata*. Se colectaron individuos durante los veranos de 2010 y 2011. Primero examinamos la estructura de la población en las cordilleras Huachuca, Santa Rita y Dragoon. Después examinamos la relación entre la estructura de la población y los factores importantes del paisaje, incluyendo la hidrología. Estos resultados son la primera parte de un estudio comparativo que examina el papel de la hidrología en la estructura de población de varias especies de anuros de las Islas Serranas.

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Conservation and management of native aquatic species of the Río Sonoyta, Sonora México. The Río Sonoyta is an important aquatic ecosystem in northern Sonora, which is disappearing because of drought and groundwater withdrawal. Its native species are also threatened by introduced species. The only watered reach is an intermittent segment (<1 km, Agua Dulce), found just across the Southern International Border from Organ Pipe Cactus National Monument (OPCNM). The native fish present in the river include the endangered Sonoyta pupfish (*Cyprinodon eremus*) and the indigenous longfin dace (*Agosia chrysogaster*). In the wild, the pupfish occurs only at Quitobaquito Springs on OPCNM and at Agua Dulce. The longfin dace may be extirpated. A partnership formed and led by the La Reserva de la Biosfera El Pinacate y Gran Desierto de Altar included partners from the United States and México to create fish refuges in México. We summarize conservation efforts to maintain native fishes in refuge ponds, report on their status, and offer suggestions for future management. We also present information on the future establishment of refuges for longfin dace and augmentation of pupfish refuges in the United States and México. We briefly discuss the impact of a new wastewater treatment plant on the Sonoyta River.

Conservación y manejo de especies acuáticas nativas del río Sonoyta, Sonora, México. El río Sonoyta es un importante ecosistema acuático en el norte de Sonora que está desapareciendo debido a la sequía y extracciones del acuífero. Sus especies nativas también están amenazadas por las especies introducidas. El único tramo con agua es un segmento intermitente (<1 km, Agua Dulce), justo al sur de la frontera internacional de Organ Pipe Cactus National Monument (OPCNM). Los peces nativos presentes en el río son: el pupo del río Sonoyta (*Cyprinodon eremus*) especie en peligro de extinción, y el charalito de aleta larga (*Agosia chrysogaster*) una especie nativa. El pupo del río Sonoyta se encuentra silvestre sólo en Quitobaquito Springs en OPCNM y en Agua Dulce. El charalito de aleta larga probablemente ha sido extirpado. La Reserva de la Biosfera El Pinacate y Gran Desierto de Altar formó y está a cargo de una asociación con miembros tanto de E.U. como de México para crear refugios para peces en México. Se presenta un resumen de los trabajos de conservación para mantener los peces nativos en las tinajas del refugio, así como un reporte de su estatus y sugerencias para el manejo futuro. También se presenta información sobre el establecimiento de refugios para el charalito de aleta larga y un aumento de refugios para el pupo del río Sonoyta tanto en E.U. como México. Por último, se discute brevemente el impacto de una nueva planta tratadora de aguas residuales en el río Sonoyta.

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Seasonal distribution of native fishes in a 10-kilometer reach of San Bernardino Creek, Sonora, México. San Bernardino Creek is a northern tributary of the Yaqui River. Originating in the United States it crosses the Southern International Border just east of Douglas, AZ/Agua Prieta, Sonora and immediately south of the San Bernardino/Leslie Canyon National Wildlife Refuge. Six of the eight Yaqui river fish species are found in this reach and include four minnows, a sucker, and a poeciliid. Information is presented on the annual and seasonal distribution of these fishes during 2010 - 2011. The Yaqui chub population is discussed in more detail including a population estimate of this species. A brief history of the area is given and the use of gabion construction to change this stream during the last 3 decades is presented.

Distribución estacional de peces nativos en un tramo de 10 km del arroyo San Bernardino, Sonora, México. El arroyo San Bernardino es un afluente norteño del río Yaqui. Nace en Estados Unidos y cruza la frontera internacional justo al este de Douglas, Arizona y Agua Prieta, Sonora y directamente al sur de los Refugios Nacionales de Vida Silvestre San Bernardino y Leslie Canyon. En este tramo se encuentran seis de las ocho especies de peces del río Yaqui: cuatro carpitas, el matalote y un poeciliido. Se presenta información en la distribución anual y estacional de estos peces durante 2010-2011. Se hace una estimación de la población de la carpa púrpura. Y se incluye una breve historia del área y la construcción de presas de gaviones para mejorar este afluente.

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Changes of riparian and desert vegetation after cattle removal in the San Bernardino Valley, Arizona/ México. The San Bernardino Valley of Arizona, USA, and Sonora, México, is one of the principal headwaters of the Río Yaqui. Conservation efforts centered on the unique aquatic organisms and habitats found in this river system have resulted in a landscape-scale experiment. Cattle were removed from the San Bernardino National Wildlife Refuge, Arizona, in 1979 and from the Rancho San Bernardino, México, in 2000. These adjoining areas experience the same yearly climatic variation and have similar soils and potential flora, yet differ in time since grazing. Permanent plots established on 2000 and 2004 show vegetation differences are greater among mesic habitats in recently grazed and long-term ungrazed plots than in xeric habitats. Plant species richness in xeric habitats (desertscrub and grassland) is greater than it is mesic habitats (riparian and mesquite bosque), but there is little difference in richness among xeric habitats in recently grazed and long-term ungrazed areas. It is unclear if this pattern is the result of minimal grazing away from water sources or reduced succession rate. Species richness in riparian habitats declines in time with grazing increases. Given that the riparian area was desert marsh in the last century, ongoing restoration efforts should continue to result in fewer plant species as succession proceeds in habitats with permanent water.

Cambios en vegetación desértica y ribereña después del desalojo de ganado en el valle de San Bernardino en Arizona y México. El valle de San Bernardino de Arizona, E.U. y Sonora, México, es uno de los principales afluentes del río Yaqui. Los trabajos de conservación de hábitats y organismos acuáticos exclusivos de este río han resultado en un estudio comparativo de diversidad florística. El ganado se desalojó de San Bernardino National Wildlife Refuge, Arizona en 1979 y del Rancho San Bernardino, México en 2000. Estas áreas colindantes tienen la misma variación climática anual, así como suelos similares y flora potencial, pero difieren en el tiempo que tienen sin ganado. Las parcelas permanentes establecidas en 2000 y 2004 muestran que las diferencias de vegetación son mayores entre hábitats húmedos con pastoreo reciente y parcelas con largo tiempo sin pastorear, que en hábitats áridos. La diversidad de la flora de hábitats áridos (matorral desértico y pastizal) es mayor que en los hábitats húmedos (ribereño y bosque de mesquite). Sin embargo, hay muy poca diferencia entre la diversidad de hábitats áridos con pastoreo reciente y áreas áridas con mucho tiempo sin pastorear. Basado en los resultados, no está claro si este patrón es el resultado de un pastoreo mínimo lejos del agua o de un rango de sucesión reducido. La diversidad de especies en hábitats ribereños disminuye con el tiempo conforme aumenta el pastoreo. Dado que el área ribereña fue un humedal del desierto el siglo pasado, la restauración continuará produciendo menos especies de plantas conforme la sucesión continua en los hábitats con agua permanente.

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Regional diversity of bees in northeastern Sonora, México and southeastern Arizona, USA. Museum records have long indicated that the xeric areas of North America are unusually rich for bees (Hymenoptera: Apiformes). Two areas of the Sky Islands where bees have been most intensively collected are the Chiricahua Mountains, Arizona, and the San Bernardino Valley, Arizona/ Sonora. Opportunistic bee sampling from the Chiricahua Mountains date back decades and have spanned from desert to pine forest ecosystems. Intensive standardized bee sampling in the San Bernardino Valley began recently (2000) and has been limited to a 20 km² area of Chihuahuan desertscrub. Species density in this area is greater than that documented elsewhere in the world; ca. 1/10th of the total bee species in the United States occur here. Species diversity is elevated in part because of high spatial and temporal turnover of species. Despite the proximity and near continuous distribution of desertscrub habitat between these two areas, bee species composition changes considerably and differences within this desert ecosystem are comparable to those that occur among ecosystems at higher elevations. Our preliminary analysis indicates regional processes such as the intersection of ecoregions strongly influence bee species diversity and that topographic complexity and differences in the spring and late summer fauna are also involved.

Diversidad regional de abejas en el noreste de Sonora, México y sureste de Arizona, E.U. Los registros de museos han indicado repetidamente que las áreas secas de América del Norte tienen una diversidad de abejas (Hymenoptera: Apiformes) excepcional. La Sierra Chiricahua en Arizona y el valle de San Bernardino en Arizona y Sonora son dos áreas de las Islas Serranas donde las abejas se han colectado de forma intensa. El muestreo oportunístico de abejas en la Sierra Chiricahua se ha realizado durante varias décadas y abarcado desde ecosistemas de desierto a los de bosque de pino. Un muestreo de abejas, intensivo y estándar, en el valle de San Bernardino empezó recientemente (2000) y se ha restringido a un área de 20 km² de matorral del desierto Chihuahuense. La densidad de especies en esta área es mayor que la documentada en otras partes del mundo; alrededor de un 1/10 del total de especies de abejas de Estados Unidos ocurre aquí. La diversidad de especies es elevada debido en parte a un alto movimiento de especies temporal y espacial. A pesar de la cercanía y la casi continua distribución de hábitat de matorral desértico entre estas dos áreas, la composición de especies de abejas cambia considerablemente y las diferencias dentro de este ecosistema de desierto son comparables a las que ocurren entre ecosistemas de elevaciones más altas. Nuestros análisis preliminares indican que los procesos regionales tales como la intersección de ecoregiones tienen una fuerte influencia en la diversidad de especies de abejas y también intervienen la complejidad topográfica y las diferencias entre la fauna de primavera y de finales del verano.

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Paleoenvironmental perspective for understanding the development, stability and state-changes of ciénegas in the American Deserts. As persistent wetlands in arid regions, ciénegas represent important resources for the maintenance and preservation of regional biodiversity. The history of ciénegas in the American Southwest over the last 8,000 years provides information on the dynamics of growth, longevity, and stability of these habitats under previous climate conditions. Proxy data such as sedimentology, pollen, charcoal, and isotopes preserved in ciénega sediments provide information on the formation, disturbance, resilience and state changes within these systems. This long-term perspective is compared to the recent history of degradation observed in the region. We present information on how the paleoenvironmental record of change can be used in conservation, restoration and management of ciénegas.

Perspectiva paleo-ambiental para entender el desarrollo, estabilidad y cambios en las ciénegas de los desiertos americanos. Por ser humedales persistentes en regiones áridas, las ciénegas representan recursos importantes para mantener y preservar la biodiversidad regional. La historia de las ciénegas en el suroeste americano durante los últimos 8000 años aporta información sobre la dinámica de crecimiento, longevidad y estabilidad de estos hábitats bajo las condiciones de climas del pasado. Datos indirectos como sedimentología, polen, carbón vegetal e isótopos preservados en los sedimentos de la ciénega proporcionan información sobre la formación, perturbación, resistencia y cambios en estos sistemas. Esta perspectiva a largo plazo es comparada con la historia reciente de degradación en la región. Se presenta información de como el registro paleo ambiental de cambios puede utilizarse en la conservación, restauración y manejo de las ciénegas.

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Responding to climate change impacts in the Sky Island Region: From planning to action. Addressing the growing impacts of climate change on natural resources requires multiple organizations, agencies, and institutions working cooperatively to incorporate climate change into resource management. In the Sky Island region of the southwestern United States and northern Mexico, Sky Island Alliance, a non-governmental organization, is leading the convening of a series of climate change adaptation workshops in cooperation with a variety of agencies and organizations. This paper demonstrates a process and methodology for convening federal and state agencies, local governments, non-profit organizations, tribal representatives, private landowners, and academic researchers in order to develop, on-the-ground and policy-level actions through climate change adaptation planning. Key outcomes of the workshops include: identification of climate change threats to and vulnerabilities of Madrean Forest, Riparian, Desert and Grassland ecosystems in the Sky Island region; analysis of direct and indirect climate change threats and interacting factors; a list of ecosystem specific adaptation options for the region, a plan for implementation of one adaptation strategy and development of a regional network of professionals working cooperatively to improve natural resource management under changing conditions. This paper highlights one approach for addressing the management and conservation challenges posed by climate change through collaborative engagement at a regional scale.

Respondiendo al impacto del cambio climático en la Región de las Islas Serranas: De la planificación a la acción. Enfrentar los crecientes impactos del cambio climático requiere múltiples organizaciones, agencias, e instituciones trabajando cooperativamente para incorporar el cambio climático al manejo de recursos. En la región de las Islas Serranas en el suroeste de Estados Unidos y el norte de México, Sky Island Alliance, una organización no gubernamental, desarrolla una serie de talleres de adaptación al cambio climático, en colaboración con varias agencias y organizaciones. Este trabajo explica el proceso y metodología para convocar agencias federales y estatales, gobiernos locales, organizaciones sin fines de lucro, representantes tribales, propietarios privados, e investigadores académicos a fin de desarrollar acciones prácticas y normativas para la adaptación al cambio climático. Los resultados principales de los talleres son: identificación de las amenazas del cambio climático y la vulnerabilidad de los ecosistemas del bosque madrense, ripario, desértico y de pastizal en la región de las Islas Serranas; análisis de las amenazas directas e indirectas del cambio climático y los factores que interactúan; listado de opciones de adaptación específicas del ecosistema para la región; plan para la implementación de una estrategia de adaptación y desarrollo de una red regional de profesionales trabajando cooperativamente para mejorar la gestión de los recursos naturales en condiciones cambiantes. Este documento pone de relieve un enfoque para abordar los desafíos de gestión y conservación que plantea el cambio climático a través de un compromiso de colaboración a escala regional.

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Population status of prairie dogs (*Cynomys ludocivianus*) in the San Pedro River Basin, Sonora. The black tailed prairie dog (*Cynomys ludocivianus*) is a species of interest for Mexico, the United States and Canada. Populations in Mexico are considered at risk, including those in Sonora, such populations require additional conservation efforts to maintain them long term. Our objective was to determine population size and density of the Sonoran colonies to establish a new colony. The prairie dog colonies are 92.32 ha for La Mesa and 57.86 ha for Las Palmitas respectively. Density was calculated using visual transect counts, and Distance sampling software for the analysis of the data. La Mesa was surveyed between November 2010 and November 2011, and las Palmitas from May to November 2011. Our density estimates range from 1.03 to 5.29 ind/ha with an average density of 3.09 ind/ha, and an estimated population of 285.26 individuals. In the case of Las Palmitas densities ranged from 1.50 to 6.45 ind/ha with an average density of 3.62 ind/ha and an estimated population of 209.45 individuals. Our results support a controlled but limited translocation effort that will allow the establishment of a new colony at Los Fresnos private reserve, consequently increasing the resilience and survivorship of black-tailed prairie dogs in Sonora.

Estado de la población de perritos de la pradera (*Cynomys ludocivianus*) en la cuenca del río San Pedro, Sonora. El perrito de las praderas de cola negra (*Cynomys ludocivianus*) es una especie de interés para México, Estados Unidos y Canadá. Poblaciones en México se consideran en situación de riesgo, incluidas las de Sonora, estas poblaciones requieren esfuerzos de conservación adicionales para mantenerlas a largo plazo. Nuestro objetivo fue determinar el tamaño y la densidad de las poblaciones de las colonias de Sonora para establecer una nueva colonia. Las colonias de perritos de la pradera son 92.32 hectáreas en La Mesa y 57.86 ha en Las Palmitas, respectivamente. La densidad fue calculada utilizando conteos visuales en transectos, y se utilizó software de muestreo a distancia para el análisis de los datos. La Mesa se monitoreó entre noviembre de 2010 y noviembre de 2011, y Las Palmitas de mayo a noviembre de 2011. Nuestras aproximaciones de densidad están en el rango de 1.03 a 5.29 ind / ha con una densidad media de 3.09 ind / ha y una población estimada de 285.26 individuos. En el caso de Las Palmitas densidades variaron desde 1.50 hasta 6.45 ind / ha con una densidad media de 3.62 ind / ha y una población estimada de 209.45 individuos. Nuestros resultados apoyan un traslado controlado pero limitado, que permitirá la creación de una nueva colonia en la reserva privada de Los Fresnos. Y así aumentar la resiliencia y la supervivencia del perrito de las praderas de cola negra en Sonora.

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The Desert Landscape Conservation Cooperative: Linking science to management. The Desert Landscape Conservation Cooperative (LCC) is a self-directed, non-regulatory partnership that covers the Mojave, Sonoran, and Chihuahuan Deserts. The Bureau of Reclamation (Reclamation) provides overall coordination of the Desert LCC, and the Fish and Wildlife Service provides a permanent Science Coordinator to provide coordination and synthesis of science activities. The Steering Committee consists of 26 members from state agencies, tribes, non-governmental organizations, and federal agencies in the U.S. and Mexico. The primary mission of the Desert LCC is linking science to management to address climate change and other broad scale stressors. The Madrean Archipelago is particularly vulnerable to climate change impacts. The Desert LCC (through Reclamation) has funded the Sky Islands Alliance to conduct a survey of springs and seeps in that area in relation to climate change. Other projects that are currently underway are analyses of climate change on major river systems (as part of Reclamation's West-Wide Climate Risk Assessments), a climate change vulnerability assessment of plant communities in the Mojave and Sonoran Deserts (as part of Fish and Wildlife Service collaboration with NatureServe), mapping of surface waters in the Sonoran Desert (U.S. Geological Survey and University of Arizona), and 8 other projects recently funded by Reclamation's WaterSMART program.

Cooperativa de conservación de paisajes del desierto: uniendo la ciencia con el manejo. La cooperativa de conservación de paisajes del desierto (LCC por sus siglas en inglés) es una asociación independiente, no normativa, que cubre los desiertos Mojave, Sonorense y Chihuahuense. La Oficina de Rehabilitación ofrece la coordinación de la LLC del desierto y el Servicio de Pesca y Vida Silvestre ofrece un coordinador científico permanente y síntesis de actividades científicas. El comité directivo consiste de 26 miembros de agencias estatales, tribus, organismos no gubernamentales y agencias federales en E.U. y México. El objetivo principal de la LLC del desierto es conectar la ciencia con el manejo para abordar el cambio climático y otros eventos con impacto a gran escala. El Archipiélago Madrense es particularmente vulnerable al impacto del cambio climático. La LLC del desierto (mediante la Oficina de Rehabilitación) ha financiado a Sky Islands Alliance para un estudio de manantiales en el área y efectos del cambio climático. Otros proyectos en curso son el análisis del impacto del cambio climático en sistemas fluviales principales (como parte de la evaluación del riesgo climático en el oeste por parte de la Oficina de Rehabilitación), evaluación de la vulnerabilidad de comunidades vegetales al cambio climático en los desiertos Mojave y Sonorense (como parte de una colaboración entre el Servicio de Pesca y Vida Silvestre y NatureServe), trazado de mapas de aguas superficiales en el Desierto Sonorense (University of Arizona y el Servicio Geológico de Estados Unidos) y otros 8 proyectos recientemente financiados por el programa WaterSMART de la Oficina de Rehabilitación.

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The Arizona Sky Island Arthropod Project (ASAP): systematics, biogeography, ecology, and population genetics of ground-dwelling arthropods. The Arizona Sky Island Arthropod Project (ASAP) is a new research program that combines systematics, biogeography, ecology, and population genetics to study ground-dwelling arthropod diversity, abundance, distribution and community structure along elevation gradients and among mountain ranges in the desert Southwest. Ground-dwelling arthropods represent taxonomically and ecologically diverse organisms that drive key ecosystem processes. Using data from museum specimens and material collected from long-term pitfall trap monitoring, ASAP will document diversity patterns across the Sky Islands to identify patterns of endemism, phylogeography, and the evolutionary origins of arthropods in these communities. In addition, ASAP will utilize the natural laboratory provided by the Sky Islands to evaluate the ecological roles of arthropods across elevational and environmental gradients on the mountains. Baseline data will be used to determine climatic boundaries for target species, which will then be integrated with climatological models to predict future changes in arthropod communities and distributions in the wake of rapid climate change. Here, we introduce this project, outline its overarching goals, and present historical data on Sky Island ground-dwelling arthropods harvested from the University of Arizona Insect Collection. In talks following this one, collaborators will present analyses of data collected during the first year of ASAP on various aspects of this multidisciplinary project.

Proyecto de Artrópodos de las Islas Serranas de Arizona (ASAP): Sistemática, biogeografía, ecología y genética de poblaciones de artrópodos terrestres. El Proyecto de Artrópodos de Las Islas Serranas de Arizona (ASAP) es un nuevo programa de investigación que combina la sistemática, biogeografía, ecología y genética de poblaciones para estudiar la diversidad, abundancia, distribución y estructura de comunidades de artrópodos terrestres a lo largo de gradientes altitudinales y entre cadenas montañosas en el desierto del suroeste norteamericano. Los artrópodos terrestres representan organismos taxonómica y ecológicamente diversos que impulsan procesos clave en el ecosistema. Utilizando datos de especímenes de museo y material colectado en monitoreos de largo plazo con trampas de caída, ASAP documentará los patrones de diversidad a través de las Islas Serranas para identificar los patrones de endemismo, filogeografía, y los orígenes evolutivos de los artrópodos en estas comunidades. Además, ASAP utilizará el laboratorio natural proporcionado por las Islas Serranas para evaluar las funciones ecológicas de los artrópodos a través de gradientes altitudinales y ambientales en las montañas. Los datos de referencia se utilizarán para determinar los límites climáticos de las especies en observación, y se integrarán con modelos climáticos para predecir los cambios futuros en las comunidades de artrópodos y su distribución después de un cambio climático rápido. Se describirá este proyecto y sus objetivos generales, y presentaremos datos históricos sobre los artrópodos terrestres de las Islas Serranas, preservados en la Colección de Insectos de la Universidad de Arizona. En subsecuentes charlas, los colaboradores mostrarán análisis de los datos obtenidos durante el primer año de ASAP en diversos aspectos de este proyecto multidisciplinario.

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Burned saguaro: Will they live or die? Thousands of acres in giant saguaro (*Carnegiea gigantea*) habitat of the Sonoran Desert continue to be scorched by fire. Resource managers struggle to maintain scenic landscapes featuring majestic saguaro with the challenges of recreation, fire, non-native species invasion and millions of annual visitors. Successfully managing this iconic saguaro community requires understanding fire resilience or intolerance. Our study compares survival of 164 saguaro 10 years after two wildfires and illustrates fire's negative consequences. Six 350 m point quarter transects were randomly placed in burned and unburned areas of The Rolls, Mesa District, Tonto National Forest, Arizona. Four saguaros were measured at each of 8 points spaced 50 m apart along each transect. Ten years post-fire, high saguaro mortality and stunted growth were observed in both burns. Saguaro mortality was 32% with apical height growth of 0.9 m after the Vista View Fire compared to 51% and 0.6 m after the nearby River Fire. Unburned areas had 4% saguaro mortality and apical growth of 1.13 m. High compared to low fire severity nearly doubled saguaro mortality and stunted growth of surviving saguaro by 30%. Protracted saguaro regeneration mandates proactive fire management to sustain this cactus-shrub community. Twenty year follow-up surveys can substantiate longer-term fire effects on this keystone species.

Sahuaros quemados, ¿vivirán o morirán? Miles de hectáreas de hábitat del sahuaro (*Carnegiea gigantea*) en el Desierto Sonorense siguen siendo arrasadas por incendios. El personal de manejo de recursos lucha por mantener los paisajes pintorescos de majestuosos sahuaros enfrentando los desafíos de recreación, fuego, invasión de especies introducidas y millones de visitantes anuales. El manejo exitoso de esta comunidad emblemática de sahuaros requiere comprender la resistencia o intolerancia a los incendios. Nuestro estudio compara la supervivencia de 164 sahuaros 10 años después de dos incendios forestales, e ilustra las consecuencias negativas de los incendios. Seis transectos de punto de 350m se ubicaron al azar en zonas quemadas y sin quemar del área The Rolls, Distrito de Mesa, Bosque Nacional de Tonto, Arizona. Cuatro sahuaros se midieron en 8 puntos separados por 50 m de distancia en cada transecto. Diez años después del incendio se observó alta mortalidad y retraso de crecimiento de sahuaros en ambas zonas quemadas. La mortalidad de sahuaros fue de 32% con un crecimiento apical de 0.9 m después del incendio de Vista View en comparación con el 51% y 0.6 m después del incendio cercano de River. Las zonas sin quemar tuvieron una mortalidad de 4% y crecimiento apical de 1.13 m. Alta severidad comparada con baja severidad del incendio casi duplicó la mortandad de sahuaros y retrasó el crecimiento de sahuaros sobrevivientes en un 30%. La regeneración prolongada de sahuaro requiere la prevención de incendios para mantener esta comunidad de cactus-arbusto. Monitoreos cada veinte años pueden corroborar los efectos a largo plazo por incendios en esta especie clave.

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Estimating flow frequency and infiltration volumes in intermittent streams in southern Arizona. Directional climate change may lead to increased aridity and fewer precipitation events across the American southwest. Determining infiltration fluxes during monsoonal rainstorms may be the key to predicting how changing precipitation frequency will affect groundwater percolation and potential recharge. Our study focuses on the following research question: How much water flows and infiltrates during storm events in ephemeral streams? In order to address these topics, twelve intermittent stream sections in southern Arizona have been chosen for infiltration flux analysis. These streams have been instrumented with temperature and electrical resistivity loggers which can detect flow and be used to estimate percolation rates in the subsurface. Data collection has yielded several months of background diurnal cycles and clear changes in variable saturation which preliminarily suggest infiltration rates on the scale of 10^{-5} m/s at peak flow. Each of the twelve stream reaches in this study fall across different flowpaths, geology, vegetation, and precipitation frequency, which dictate the dynamics between the hydrology and ecosystem processes. The hydrological aspect of this study is partnered with a vegetation analysis and an entomological study in order to develop a comprehensive investigation of the complex characterization of variably saturated environments.

Estimación de la frecuencia de caudales y volumen de infiltración en arroyos intermitentes en el sur de Arizona. El cambio climático direccional puede ocasionar un aumento de aridez y menor precipitación en el Suroeste Norteamericano. Determinar los flujos de infiltración durante las tormentas del monzón puede ser la clave para pronosticar como el cambio de frecuencia de la precipitación afectará la filtración y la potencia de recargar el acuífero. Nuestra investigación se enfoca en la siguiente pregunta: ¿Cuánta agua fluye y se infiltra durante las tormentas en los arroyos efímeros? Con el fin de abordar este tema se escogieron doce arroyos intermitentes del sur de Arizona para un análisis del flujo de infiltración. Se colocaron instrumentos electrónicos que registran temperatura y resistencia eléctrica para detectar el caudal, y así calcular las tasas de filtración en el subsuelo. La toma de datos arrojó un historial de ciclos diurnos de varios meses y cambios evidentes de la saturación variable donde los resultados preliminares muestran tasas de infiltración en una escala de 10^{-5} m/s durante el caudal máximo. Cada uno de los doce tramos de arroyos en esta investigación tiene diferente cauce, geología, vegetación y frecuencia de lluvias, que dictan la dinámica entre la hidrología y los procesos del ecosistema. El aspecto hidrológico de esta investigación está ligado con un análisis de vegetación y un estudio entomológico con el fin de desarrollar una investigación exhaustiva de las características complejas de ambientes de saturación variable.

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Fire and forest dynamics along an elevational gradient of the Pinaleno Mountains of Arizona. Fire and climate are important drivers of forest dynamics in North America. Studies of fire activity along elevational gradients provide an opportunity to examine how fire spreads among

stands of different species assemblages, and how climate, topography, and stand conditions influence fire behavior. We are examining spatial and temporal distributions of fire and species dynamics in ponderosa-oak, mixed conifer, and spruce-fir forests of the Pinaleno Mountains. Dendroecological reconstructions are based on sampling trees from a grid of 78 plots covering the area above 7,000 ft. elevation (2,134 meters). Within and around plots we systematically sampled trees with fire scars. Preliminary results from 1,211 plot trees and 110 fire-scarred samples, suggest distinct patterns of seedling recruitment and differences in fire frequency and severity in adjoining forest types prior to 1900. Post 1900 seedling recruitment shows synchrony across forest assemblages, suggesting a shift from stand-level to landscape level controls. Pulses of seedling recruitment and exclusion of fire from lower elevation dry forests has resulted in forest structure that facilitates fire spread among forest types with very different historical fire regimes. These structural and compositional changes have implications for tree recruitment and longevity, retention of fire-adapted species, and resilience following future disturbances.

Dinámica de incendios y bosques en un gradiente altitudinal de la cordillera Pinaleno de Arizona. Fuego y clima son factores importantes de la dinámica de bosques en América del Norte. Los estudios de actividad del fuego en gradientes de elevación proporcionan una oportunidad para examinar cómo el fuego se propaga entre lugares con asociaciones de especies diferentes, y cómo el clima, topografía, y condiciones del área influyen en el comportamiento del fuego. Estamos examinando la distribución espacial y temporal de la dinámica de incendios y especies en bosques de ponderosa-encino, coníferas mixtas y picea-abies de la Sierra Pinaleno. Reconstrucciones dendroecológicas están basadas en el muestreo de árboles de una cuadrícula de 78 parcelas que cubren el área arriba de 2,134 m de elevación. Dentro y alrededor de las parcelas se hizo un muestreo sistemáticamente de árboles con cicatrices de fuego. Los resultados preliminares de 1,211 árboles y 110 muestras con cicatrices de fuego, sugieren distintos patrones de reclutamiento de plántulas y diferencias en frecuencia y severidad de incendios en los bosques adyacentes antes de 1900. Después de 1900 el reclutamiento de plántulas muestra sincronía en los ensambles del bosque, lo que sugiere un cambio del control a nivel localizado a influencia a nivel de paisaje. Los pulsos de reclutamiento de plántulas y la exclusión de incendio de bosques secos de baja elevación ha ocasionado una estructura del bosque que facilita la propagación del fuego entre tipos de bosques con regímenes históricos de incendios muy diferentes. Estos cambios estructurales y de composición tienen implicaciones para el reclutamiento y longevidad de árboles, la retención de especies adaptadas al fuego, y la capacidad de recuperación de futuros disturbios.

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Streamflow variability of dryland rivers in a changing climate. Ephemeral and intermittent streams in the southwestern United States exist in a precarious balance between drying and flooding. Although dryland streams are already naturally fragmented ecosystems, there is concern of further habitat loss and decreased longitudinal connectivity associated with more frequent and severe droughts caused by climate change and greater human appropriation of water resources. Characterizing the considerable spatiotemporal variability in streamflow, both today and into the future, remains a paramount challenge. Using a spatial array of electrical resistance sensors, we quantified streamflow continuity (continuous through time) and longitudinal connectivity (continuous through space) across watersheds in the Huachuca Mountains, Arizona. Continuous monitoring revealed that stream reaches are characterized by a range of hydrologic flow permanence, and that continuous streamflow in intermittent and ephemeral reaches accounted for <30% and <5% of the year, respectively. Canyon-wide longitudinal connectivity and reach-level flow continuity was rare. Comparison of streamflow patterns between 2010 (“normal/wet”) and 2011 (“dry”) water year showed that decreases in winter and spring precipitation can result in earlier stream drying, with shifts from perennial to intermittent or intermittent to ephemeral flow regimes. Rain-runoff modeling demonstrated significant potential for losses in habitat availability and depressed longitudinal connectivity according to climate change.

Variabilidad de caudal de ríos de zonas áridas en un clima cambiante . Los arroyos efímeros e intermitentes del suroeste de Estados Unidos subsisten en un equilibrio precario entre sequía e inundaciones. Aunque los arroyos de zonas áridas son ecosistemas fragmentados por naturaleza, existe la preocupación de una mayor pérdida de hábitat y la disminución de la conectividad longitudinal, asociada con sequías más frecuentes y severas ocasionadas por el cambio climático y un mayor uso humano de recursos hídricos. Caracterizar la variabilidad espacio-temporal de estos caudales, tanto hoy como en el futuro, es un desafío primordial. Con sensores de resistencia eléctrica se cuantificó la continuidad de caudales (continua en el tiempo) y la conectividad longitudinal (continua en el espacio) en las cuencas hidrográficas de la Sierra Huachuca, Arizona. El monitoreo continuo reveló que los tramos de arroyos se caracterizan por una oscilación de permanencia del flujo hidrológico, y el caudal continuo en tramos intermitentes y efímeros representan <30% y <5% del año, respectivamente. La conectividad longitudinal a lo ancho de cañones y continuidad de corrientes en tramos fue escasa. Comparación de los patrones de caudales entre los años 2010 (“normal / húmedo”) y 2011 (“seco”) demostró que la disminución de precipitación de invierno y primavera puede causar que los arroyos se sequen más pronto, con cambios en los regímenes de corrientes perennes a intermitente o de intermitente a efímeras. Los modelos de lluvia-escorren indican un potencial significativo de pérdidas en la disponibilidad de hábitat y una conectividad longitudinal baja de acuerdo al cambio climático.

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Avifauna of the San Bernardino Ranch, Agua Prieta, Sonora, Mexico. The interest and research on grassland birds have increased in recent decades due to the decline of many of their populations and the fragmentation or loss of their habitats. The San Bernardino Ranch is located in desert grassland in northeastern Sonora. For 10 years restoration activities have been conducted because previous economic activities deteriorated the habitat. Therefore, it is important to develop annual lists of flora and fauna that can help evaluate the degree of restoration. As part of

the Professional Practices program at the Universidad de Sonora, we conducted a taxonomic list of birds observed on the ranch in the summer of 2011. During that season, we found a total of 53 species and 42 genera in 26 families. The sampling will be repeated during the winter to estimate the number of migratory birds that find refuge on the ranch. With the complete record of the birds, we will learn about the effect of habitat restoration in the area on the diversity of birds and species of concern for conservation.

Avifauna del rancho San Bernardino, Agua Prieta, Sonora, México. El interés y las investigaciones sobre las aves de pastizal se han incrementado en las últimas décadas, debido a la declinación de muchas de sus poblaciones y a la fragmentación o pérdida de sus hábitats. El rancho San Bernardino se encuentra en la región de pastizal desértico en el noreste de Sonora; desde hace 10 años se han llevado a cabo acciones de restauración, antiguamente se realizaban actividades económicas que deterioraban el hábitat. Por esto, es importante elaborar listados anuales de fauna y flora que nos puedan proporcionar el grado de restauración del lugar. Como parte de las prácticas profesionales de biología, durante el verano de 2011 se elaboró un listado taxonómico de la avifauna que alberga el rancho, durante esa estación del año se encontraron un total de 53 especies y 42 géneros distribuidos en 26 familias. Este mismo muestreo se llevará a cabo durante el invierno y de esta manera será posible estimar la cantidad de aves migratorias que encuentran refugio en el rancho. Con el registro completo de las aves, se obtendrá información sobre el impacto del grado de restauración del hábitat en la zona en la diversidad de aves y las especies de interés para la conservación.

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Moth inventory of Rincón de Guadalupe, Sierra de Bacadéhuachi, Sonora, México. Moths were sampled in 2011 on two Madrean Archipelago Biodiversity Assessment (MABA) trips to the historic Rincón de Guadalupe Catholic Diocese camp in the Sierra de Bacadéhuachi in the westernmost Sierra Madre Occidental (SMO) in east-central Sonora México. The study area is in Arroyo Campo los Padres, 16.5 km (by air) east-northeast of Bacadéhuachi. The habitat is pine-oak forest (POF) at 1680 m elevation. A trip in August during the peak of the rainy season documented many sphingid, saturniid, and arctiid moth species typical of POF, including many previously known no farther north than the Yécora area ca. 160 km to the south. Of special interest were a number of species associated with tropical deciduous forest, which normally live at lower elevations. A trip in early September yielded a great diversity of smaller moths, especially those in the Noctuidae, which feed on flowers in the larval stage. Both sampling periods resulted in more than 200 species documented on each trip, with a total of more than 400 species. The moth fauna of the area reflects a dramatic convergence of species from the Rocky Mountains, the montane SMO forests, and the tropical lowlands of northwestern México. At least 12 species have been determined to be new to science and await description. The remarkable species richness of moths, the unspoiled natural beauty of the area, and the rich cultural history make this area a standout for preservation.

Inventario de las palomillas del Rincón de Guadalupe, Sierra de Bacadéhuachi, Sonora, México. Las palomillas fueron muestreadas en 2011 durante dos expediciones del proyecto Evaluación de la Biodiversidad del Archipiélago Madreño (MABA) al campamento histórico Rincón de Guadalupe, de la Diócesis Católica, en la Sierra de Bacadéhuachi al oriente centro de Sonora, México. La ubicación del área de estudio es en el Arroyo Campo los Padres, a 16.5 km (por aire) este-noreste de Bacadéhuachi. El hábitat es bosque de pino-encino (BPE) a 1680 m de elevación. El primer viaje en agosto durante la temporada alta de la estación lluviosa produjo varias especies de esfingidos, saturnidos y arctiidos típicas de BPE, entre ellas varias especies conocidas previamente no más al norte del área de Yécora en la Sierra Madre Occidental (SMO) ca. de 160 km al sur. De especial interés son varias especies asociadas con la selva baja caducifolia, que normalmente viven en elevaciones más bajas. En el segundo viaje a principios de septiembre se documentó una gran diversidad de palomillas pequeñas, en especial especies del género noctuid, las que se alimentan de flores en su fase de larva. Los dos períodos de muestreo dieron como resultado más de 200 especies documentadas en cada excursión, para un total de más de 400 especies. La fauna de palomillas del área refleja una convergencia dramática de especies de las Montañas Rocosas, los bosques de montaña de la SMO y las regiones cálidas tropicales del noroeste de México. Por lo menos 12 especies se han identificado como nuevas para la ciencia y se espera su descripción. Por su extraordinaria diversidad de especies de palomillas, belleza natural y rica historia cultural este lugar debe protegerse.

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Ursus in a Sky Island range: The impact of drought and human activity on black bears in the Huachuca Mountains since 2004. At the Madrean Archipelago II Conference, the author presented a twenty-year analysis (1983-2004) of black bear mortality in the Huachuca Mountains. This presentation will provide updated information on black bear mortality numbers and causes of mortality from 2005 through 2012, linking this information to the drought conditions that have continued to plague the Sky Islands. This presentation will include an analysis of the events of the fall and summer of 2006 when no less than 21 bears – over 40% of the total population – were killed or removed from the Huachuca Mountains. Also included will be additional observations and comments regarding the role humans play in black bear mortality in the Huachuca Mountains. The data presented in this presentation was collected through an analysis of Arizona Game and Fish records, rainfall data provided by Fort Huachuca, newspaper articles, and personal interviews and communication with wildlife managers, bear biologists, local landowners, and others. Among the results of this presentation will be data suggesting that far too many bears – especially females – are being removed from the Huachuca Mountains, and that in light of recent drought, wildlife managers need to explore alternate means of managing bears in this unique Madrean Archipelago population.

Ursus en una cordillera de Islas Serranas: impacto de la sequía y la actividad humana en osos negros en la Sierra Huachuca desde 2004. En el II Congreso del Archipiélago Madreño, el autor presentó un análisis de veinte años (1983-2004) de la mortalidad del oso negro en la Sierra de Huachuca. Esta presentación aportará información actualizada sobre registros y causas de mortalidad de osos negros a partir de 2005 hasta el 2012, vinculando esta información a las condiciones de sequía que han seguido afectando las Islas Serranas. Esta presentación

incluirá un análisis de los acontecimientos del otoño y verano de 2006, cuando al menos 21 osos, más del 40% de la población total, murieron o se llevaron fuera de la Sierra Huachuca. También se incluirán observaciones y comentarios adicionales sobre el papel de los humanos en la mortalidad del oso negro en las montañas Huachuca. Los datos de esta investigación provienen de un análisis de registros de Arizona Game and Fish, datos de precipitación de Fort Huachuca, artículos periodísticos y entrevistas y comunicación con personal de manejo de fauna, biólogos del oso, propietarios privados, entre otros. Los resultados sugieren que demasiados osos, especialmente las hembras, se han sacado de la Sierra Huachuca, y en vista de la reciente sequía, el personal de manejo de fauna necesita explorar otras opciones de manejo para esta población de osos única del Archipiélago Madreño.

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Fire and debris flows in the Huachuca Mountains of southeastern Arizona. The occurrence of debris flows in the 2011 monsoon season following the Monument Fire in the Huachuca Mountains demonstrated again the causal linkage between wildfire and debris flows in southern Arizona. Debris flows are distinguished from water floods by their higher densities and lower viscosities, which permits them to transport large quantities of coarse sediment. Because debris flows perform more work shaping channels and moving coarse material than the combined effects of hundreds of years of water floods, they are critical agents in shaping the watersheds of the mountains of southern Arizona. Previous studies had documented debris flows in monsoon seasons following fires in 1977, 1988, and 2006 in the central and southern Huachucas. Vastly increased runoff from steep, moderately to highly burned watersheds led to erosion of sediment from gullies and channels and the generation of debris flows. Debris flows in the Huachucas have typically excavated nearly all sediment from steep channel reaches, suggesting that return times between debris flows in individual watersheds might be several centuries. The re-occurrence of debris flows in Miller Canyon in 2011 implies that in the modern period with fairly frequent large wildfires, the return time between debris flows may be much shorter.

Incendios forestales y flujo de detritos en la Sierra Huachuca del sureste de Arizona. El flujo de detritos durante la temporada del monzón de 2011 después del incendio forestal conocido como 'Monument Fire' en la Sierra Huachuca mostró la conexión entre incendios y flujos de detritos en el sur de Arizona. Los flujos de detritos se distinguen de las inundaciones por su alta densidad y su baja viscosidad lo que permite el transporte de grandes cantidades de sedimento grueso. Los flujos de detritos son procesos críticos en la formación de cuencas hidrográficas en las montañas del sur de Arizona ya que su efecto es mayor formando canales y moviendo material grueso que los efectos de cientos de años de inundaciones. Estudios previos, han documentado flujos de detritos en temporadas del monzón después de incendios forestales en 1977, 1988 y 2006 en las partes centrales y sureñas de la Sierra Huachuca. El gran aumento de escorrentía en cuencas empinadas con niveles de quemazón de moderados a altos causó la erosión de sedimentos de barrancos y canales y la generación de flujos de detritos. En la Sierra Huachuca los flujos de detritos típicamente han excavado casi todo el sedimento de los tramos mas empinados, sugiriendo que el flujo de detritos en cuencas individuales puede ser de varios siglos. La reaparición de flujos de detritos en Miller Canyon en 2011 sugiere que en esta era moderna con grandes incendios forestales frecuentes, el tiempo entre flujos de detritos es mas corto.

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Buying land for conservation purposes in Sonora, Mexico. The Northern Jaguar Reserve is approximately 50,000 acres, comprising the largest privately owned wildlife preserve in Sonora. Buying land in remote parts of Sonora takes special talents as ownership rules may not be clear, boundaries may not be defined in the records, there are complex legal procedures to guarantee ownership in which Letters of Intent hold special powers and special complexities for ejido lands. In addition, only a Presidential Decree can prevent mining, and ownership of riparian land—whether by governmental or private parties—is controversial. The legal framework for conservation easements is in its infancy in Sonora. The lessons learned at the NJR for conservation land purchases will be described. NJP has invited participation by additional purchasers/managers of private reserve lands in Sonora to describe their lessons learned during the Question and Answer period following the presentations. These participants will include the Cuenca los Ojos Foundation (Valer Austin) and Rancho Los Fresnos (Juan Carlos Bravo).

Compra de tierras para conservación en Sonora, México. La Reserva del Jaguar del Norte (RJN) tiene un área aproximada de 20,000 hectáreas y representa la reserva natural privada más grande de Sonora. La compra de tierras en zonas remotas de Sonora requiere talentos especiales, ya que los títulos de propiedad pueden ser confusos, los linderos muchas veces no están bien marcados y trámites legales engorrosos para garantizar el cambio de propietario, donde las cartas de intención conceden poderes especiales a terrenos ejidales. Además, sólo por decreto presidencial se pueden negar actividades mineras y propiedad de terrenos ribereños, ya sea por agencias del gobierno o privados, es objeto de controversia. El marco legal de las servidumbres ecológicas apenas empiezan en Sonora. Se presentará lo aprendido por RJN en la compra de tierras para conservación. RJN ha extendido una invitación a otros encargados de compra de terrenos y manejo de reservas privadas en Sonora para compartir experiencias durante la sesión de preguntas y respuestas. Se contará con la presencia de Fundación Cuenca los Ojos (Valer Austin) y Rancho los Fresnos (Juan Carlos Bravo).

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Managing prairie dogs, cattle and honey mesquite: Ecological implications for grassland conservation. On last decades honey mesquite (*Prosopis glandulosa*) has increased its abundance in arid grasslands of northern Mexico and southern US. This process has been attributed mainly to overgrazing by livestock and eradication of native fauna. Although herbivory by rodents has been considered as an important element in desert grasslands, it has not been given much importance as an element capable to control the shrub establishment. Our objective was to determine the independent and interactive effects of black-tailed prairie dog (*Cynomys ludovicianus*) and cattle on mesquite abundance and structure in a desert grassland ecosystem of northern Chihuahua, Mexico. Cattle and prairie dogs were simultaneously manipulated using a controlled, long-term, replicated experiment with a 2x2 factorial design. In five years, mesquite abundance increased in sites where prairie dog were removed, no matter if cattle were present or not. Prairie dogs controlled the mesquite growing and cover, but the effect increased when cattle also was present. The study of these interactions is critical to understand the role of both species on the shrub expansion and grassland conservation in order to develop better management practices in sites where both species are still present.

El manejo de perritos de la pradera, ganado y mezquite: Implicaciones ecológicas para conservación de pastizales. En las últimas décadas el mezquite (*Prosopis glandulosa*) ha incrementado su abundancia en los pastizales áridos del norte de México y sur de Estados Unidos. Este proceso se ha atribuido principalmente al sobrepastoreo por ganado doméstico y la erradicación de la fauna nativa. A pesar que la herbivoría de pequeños roedores ha sido considerada como un elemento importante en los pastizales desérticos, no se le ha dado mucha importancia como un elemento capaz de controlar el establecimiento de arbustos. Nuestro objetivo fue determinar los efectos independientes e interactivos del perrito de la pradera de cola negra (*Cynomys ludovicianus*) y ganado en la abundancia y estructura del mezquite en un ecosistema de pastizal desértico del norte de Chihuahua, México. Los perros de las praderas y el ganado doméstico fueron manipulados de forma simultánea en un experimento a largo plazo con un diseño factorial 2x2. En cinco años, la abundancia de mezquite aumentó en sitios donde los perros de la pradera se removieron, sin importar si el ganado estaba presente o no. Los perros de la pradera controlaron el crecimiento de mezquite y la cobertura, pero el efecto fue mayor cuando el ganado también estaba presente. El estudio de estas interacciones es fundamental para entender el papel que las dos especies tienen en la expansión de arbustos y la conservación de los pastizales, con el fin de desarrollar mejores prácticas de manejo en pastizales donde ambas especies todavía están presentes.

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Habitat characteristics of montane riparian bird communities in southern Arizona. In the Sky Island region of southern Arizona, mesic montane riparian areas comprise a small percentage of the landscape, yet provide habitat for a disproportionately large proportion of the region's biodiversity. This is particularly true for birds, which have higher densities and species richness in riparian areas compared to upland areas. Despite the importance of riparian areas, little research has focused on riparian areas where Sonoran desert-scrub grades into Madrean evergreen woodland. In 1997 and 1998, we surveyed birds and vegetation at 46 point-count stations in two mountain ranges, Baboquivari and Atascosa, to describe the bird community and to understand how vegetation characteristics influence bird abundance and diversity. We recorded >3,900 individuals representing 79 species and found that both vegetation structure and floristics were important in structuring the avian community. In general, areas of dense vegetation in the understory, which are common in riparian areas, were important predictors of bird diversity. In addition, strong gradients that were determined largely by the composition of dominant plant species affected the distribution and abundance of bird species in the community. Understanding the habitat associations of these species will provide additional information to make science-based management decisions.

Características del hábitat de las comunidades de aves ribereñas de montaña en el sur de Arizona. En la región de las Islas Serranas del sur de Arizona, las áreas ribereñas mesicas de montaña representan un pequeño porcentaje del paisaje, sin embargo, proporcionan el hábitat para una porción bastante grande de la biodiversidad de la región. Esto es especial para las aves, que tienen una mayor densidad y riqueza de especies ribereñas en comparación con zonas más altas. A pesar de la importancia de las áreas ribereñas, poca investigación se ha centrado en estas zonas, donde el matorral desértico sonorense cambia a bosque perenne madrense. En 1997 y 1998, monitoreamos pájaros y vegetación en 46 estaciones de monitoreo en dos cadenas montañosas, Baboquivari y Atascosa, para describir la comunidad de aves y para entender cómo las características de la vegetación influyen en la abundancia de aves y su diversidad. Registramos > 3,900 individuos de 79 especies y se encontró que tanto la estructura de la vegetación y la flora fueron importantes en la composición de la comunidad de aves. En general las áreas de densa vegetación en el sotobosque, comunes en las zonas ribereñas, fueron indicadores importantes de la diversidad de aves. Además, los fuertes gradientes que se determinaron principalmente por la composición de especies de plantas dominantes afectó la distribución y abundancia de especies de aves en la comunidad. El conocimiento de las asociaciones de hábitat de estas especies, aportará información adicional para tomar decisiones de manejo con base científica.

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Ecology and conservation of a Madrean rattlesnake, *Crotalus pricei*. Twin-spotted rattlesnakes (*Crotalus pricei*) are small-bodied snakes found in six ranges within the Madrean Archipelago as well as the Sierra Madre Occidental and Sierra Madre Oriental. Within the Madrean

Archipelago they are most common in Madrean montane conifer forest above 2400 m, making them the region's highest elevation snake. A warming, drying climatic trend is an obvious conservation concern. We monitored populations of *C. pricei* in Arizona's Chiricahua Mountains from 1997-2009 to learn about diet, reproduction, growth rates, and survival trends. We captured 306 individuals and recaptured snakes on 155 occasions. Spiny lizards (*Sceloporus*) were the most frequently taken prey for both juveniles and adults. Larger females were more likely to be gravid than smaller adult females. Our best model indicated that survival rate remained constant at our most-studied site over the 13 years; detectability varied by search effort and weather. Although there was no evidence of a population decline during our study, we identified ways in which climate change and continued illegal collection for the pet trade could pose a threat to the conservation of isolated, high elevation populations.

Ecología y conservación de una víbora de cascabel madreño, *Crotalus pricei*. Las chachamuris (*Crotalus pricei*) son víboras pequeñas que se encuentran en seis cordilleras del Archipiélago Madreño, así como en la Sierra Madre Occidental y la Sierra Madre Oriental. En el Archipiélago Madreño son más comunes en el bosque de coníferas de montaña madreño arriba de 2400 m, por lo que son la serpiente de más alta elevación en la región. Una tendencia climática de calentamiento y sequía es claramente una preocupación para su conservación. Se hizo un monitoreo de las poblaciones de *C. pricei* en la Sierra Chiricahua en Arizona de 1997-2009 para estudiar su dieta, reproducción, tasas de crecimiento y supervivencia. Se capturaron 306 individuos y se recapturaron en 155 ocasiones. El cachorón (*Sceloporus*) fue la presa más común atrapada tanto por jóvenes y adultos. Las hembras más grandes tuvieron más probabilidades de estar grávidas que las hembras adultas más pequeñas. Nuestro mejor modelo indicó que la tasa de supervivencia se mantuvo constante en nuestro sitio más estudiado en los 13 años; la detectabilidad varió basada en el esfuerzo de búsqueda y el clima. Aunque no detectamos disminución de la población en nuestro estudio, identificamos formas en las que el cambio climático y la colecta ilegal para el comercio podrían representar una amenaza para la conservación de las poblaciones aisladas de elevaciones altas.

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From genes to ecosystems and human well being: Ecological effects of climate change in Sky Islands. Climate change is causing rapid changes in mountain ecosystems. These changes may have ecological consequences at many levels of biological organization, from genetic viability of populations to landscape-level ecosystem processes. We present modeled projections of climate change in the Sky Islands bioregion, and review potential effects of these changes on ecosystems of the Madrean Archipelago Sky Islands of the US-Mexico border region as a model system. Some low elevation species may experience an expansion in suitable area, while habitat for high elevation species may contract. As a consequence, at the population level, high elevation species will be vulnerable to genetic isolation and extinction, while population size may increase for low-elevation species. At the community level, plant-animal interactions may be disrupted as species respond differentially to climate change, affecting phenology patterns, insect outbreaks, and other interactions. Ecosystem processes such as fire will be altered as changing plant distributions modify fuel loads, and as changes in temperature, wind and humidity alter the physical fire environment. Sky Island ecosystems represent important "indicator ecosystems" for monitoring ecological responses to climate change across elevation gradients.

Desde genes a ecosistemas y bienestar humano: Efectos ecológicos del cambio climático en las Islas Serranas. El cambio climático está provocando rápidos cambios en los ecosistemas de montaña. Estos cambios pueden tener consecuencias ecológicas en muchos niveles de organización biológica, desde la viabilidad genética de las poblaciones hasta los procesos del ecosistema a nivel de paisaje. Presentamos modelos del cambio climático en la bioregión de las Islas Serranas, con una síntesis de los posibles efectos de estos cambios en los ecosistemas del Archipiélago Madreño de las Islas Serranas de la región fronteriza México-Estados Unidos. Algunas especies de elevaciones bajas podrían aumentar su rango de distribución, mientras que el hábitat de especies de elevaciones altas podría reducirse. Como consecuencia, a nivel de población, las especies de elevaciones altas serán vulnerables al aislamiento genético y la extinción, mientras que el tamaño de la población podría aumentar para las especies de elevaciones bajas. A nivel comunidad, las interacciones planta-animal podrían interrumpirse ya que las especies responden de forma diferente al cambio climático, afectando patrones de fenología, plagas de insectos y otras interacciones. Los procesos del ecosistema como el fuego se alterarán ya que el cambio de distribución de plantas modificará la vegetación combustible, así como los cambios en temperatura, viento y humedad alteran el ambiente físico para incendios. Los ecosistemas de las Islas Serranas son importantes "ecosistemas indicadores" para monitorear las respuestas ecológicas al cambio climático en gradientes de elevación.

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Land management on the United States/Mexico border. Many conservation strategies have been developed by the Service in cooperation with others to protect habitat and enhance the recovery of fish and wildlife populations in the San Bernardino Valley, straddling Arizona and Sonora. Damage to habitats along this international border by various illegal activities is detrimental to species recovery. In addition, potential threats to national security have prompted the United States to improve control over the country's boundaries, creating additional challenges for land managers mandated with protecting the nation's landscapes, natural resources, and associated values. Such challenges are not insurmountable, and with minimal effort both resource management and border security can often complement one another. With or without the influence of changes along the international border, effective species recovery methods must include a coordinated approach which involves: determining and assessing the biological requirements of selected species through combinations of inventory, monitoring, and research activities; manag-

ing and protecting existing and historic habitats and populations; assessing potential reintroductions of key species into appropriate habitats; managing exotic plants and animals that threaten the recovery of desired conditions; and developing and providing information and education relative to the species, their habitats, and the ecosystems upon which all fish, wildlife, and humans depend.

Manejo de recursos naturales en la frontera de México y Estados Unidos. Muchas estrategias de conservación han sido desarrolladas por U.S. Fish and Wildlife Service y colaboradores para proteger el hábitat y mejorar la recuperación de las poblaciones de peces y fauna en el valle de San Bernardino, que se extiende a ambos lados de la frontera entre Arizona y Sonora. El daño a los hábitats causado por las diversas actividades ilegales, en esta frontera internacional, es perjudicial para la recuperación de especies. Además, las amenazas potenciales a la seguridad nacional han llevado a Estados Unidos a mejorar el control de las fronteras del país, creando retos adicionales para el personal de manejo encargados de proteger los paisajes de la nación, recursos naturales y bienes asociados. Estos retos no son insuperables, y con un mínimo esfuerzo tanto el manejo de recursos y la seguridad de la frontera a menudo se complementan entre sí. Con o sin la influencia de los cambios en la frontera internacional, métodos eficaces de recuperación de especies deben incluir un enfoque coordinado que implica identificar y evaluar los requisitos biológicos de especies seleccionadas al vincular inventarios, monitoreo y actividades de investigación; manejo y protección de hábitats y poblaciones actuales e históricas; evaluar la reintroducción potencial de especies clave en hábitats adecuados; manejo de plantas y animales exóticos que amenazan la recuperación; y el desarrollo de materiales educativos e información sobre las especies, sus hábitats y los ecosistemas de los que tanto dependen los peces, fauna y flora y los seres humanos.

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Amphibian disease and Lowland Leopard Frogs: Trials in identification, treatment, and death. Population declines of amphibians have been recorded worldwide. When two populations of lowland leopard frog became locally extirpated from the Rincon Mountains of Saguaro National Park, eggs and tadpoles of this frog were taken from the park and placed in backyard ponds nearby for potential future reintroduction. Through an unknown vector, frogs in these ponds were infected with the amphibian chytrid fungus, *Batrachochytrium dendrobatidis* ("Bd"), and in some cases had near 100% mortality each winter following initial metamorphosis due to this disease. While these backyard ponds were initially intended as ideal breeding facilities, they now provide a unique opportunity to learn more about how lowland leopard frogs interact and respond to Bd on a smaller scale, without affecting frog populations in the wild. We present findings of what we have learned about lowland leopard frogs and Bd from two backyard ponds, including identification of dead frogs, the possibility of freezing frogs found dead and later obtaining usable Bd assays from them, and the feasibility of treating wild lowland leopard frogs for Bd to help them survive the winter.

La enfermedad anfibia en ranas yavapai: pruebas de identificación, tratamiento y muerte. Se han registrado descensos de poblaciones de anfibios en todo el mundo. Cuando dos poblaciones de rana yavapai desaparecieron de las montañas Rincón del Parque Nacional Saguaro, los huevos y los renacuajos de esta rana se llevaron del parque y se pusieron en estanques de patio cercanos para su futura reintroducción. Mediante un vector desconocido, las ranas de estos estanques se infectaron con el hongo quitridio anfibio, *Batrachochytrium dendrobatidis* ("Bd"), y cada invierno después de la metamorfosis inicial se registró una mortalidad casi del 100%, en algunos casos, por causa de esta enfermedad. Aunque estos estanques originalmente pretendían ser instalaciones para la reproducción, ahora proveen una oportunidad única para aprender más sobre las interacciones de las ranas yavapai y cómo responden al Bd a menor escala, sin afectar las poblaciones silvestres. Presentamos los resultados de lo aprendido sobre las ranas yavapai y el Bd de dos estanques de patio, incluyendo la identificación de ranas muertas, la posibilidad de congelarlas y obtener de ellas muestras utilizables de Bd y la viabilidad de tratar las ranas silvestres con Bd para ayudarlas a sobrevivir el invierno.

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Institutional challenges in landscape-level fire restoration in the Sky Islands. Landscape-level management of fire transcends jurisdictional boundaries and requires participation by multiple stakeholders. This presents a broad array of ecological and social challenges that collaborative projects are emerging to address. Collaborative fire management requires scientific understanding of complex system dynamics, as well as an understanding of how to design effective partnerships, decision-making processes, and procedures to incorporate public input in management goals. Thus, there is an inherent need to consider institutions, or formal rules and social norms, in collaborative fire management. In response to the threat of increasingly severe wildfires, the Coronado National Forest recently unveiled FireScope, a collaborative program to safely manage and reintroduce fire into the Sky Islands of southeastern Arizona. This paper will discuss the unique social and institutional context facing FireScope managers and partners. Other collaborative programs have struggled because of conflict with the public, lawsuits, or breakdown in partnerships. As this collaborative arrangement develops, we will identify the unique institutional barriers that may need to be addressed to ensure desirable social and ecological outcomes. FireScope will be used as a case study to analyze the institutional barriers and opportunities inherent in achieving safe, ecologically sound, and sustainable fire management in the Sky Islands.

Retos institucionales en restauración del paisaje después de incendios en las Islas Serranas. El manejo del fuego a nivel paisaje trasciende los límites jurisdiccionales y requiere la participación de los sectores interesados. Esto representa grandes retos ecológicos y sociales por lo que están surgiendo proyectos de colaboración para enfrentarlos. El manejo colaborativo de incendios requiere la comprensión científica de la dinámica de sistemas complejos, así como la capacidad de diseñar alianzas eficaces, procesos de toma de decisiones y formas de incorporar la aportación del público en las metas de manejo. Por lo tanto es esencial considerar instituciones y normas sociales en el manejo colabo-

rativo de incendios. En respuesta a la amenaza de los incendios forestales cada vez más graves, el Bosque Nacional Coronado dio a conocer recientemente FireScape, un programa de colaboración en manejo y reintroducción sin riesgo del fuego en las Islas Serranas del sureste de Arizona. Este trabajo abordará el contexto social e institucional que enfrentan los coordinadores de FireScape y socios. Otros programas de colaboración han tenido problemas debido a conflicto con el público, demandas, o ruptura de las alianzas. Conforme este acuerdo de colaboración se desarrolla, identificaremos las barreras institucionales que es necesario abordar para garantizar los resultados ecológicos y sociales deseados. Se utilizará FireScape como caso de estudio para analizar las barreras institucionales y las oportunidades para lograr un manejo del fuego seguro, ecológicamente responsable y sostenible de las Islas Serranas.

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Flora of the Limestone Sierra Anibácachi, Municipio de Agua Prieta, Sonora. A total of 590 plants collections were made in the La Calera area in northeastern Sonora on 20 trips in 2002-2008. The 25 km² (2.5 km² extensively inventoried) area in the Sierra Anibácachi, Municipio de Agua Prieta, is 11 km south of the Arizona border (31°13'59"N 109°37'53"W, ca. 1287 m elevation). Chihuahuan desertscrub on limestone substrates is dominated by creosotebush (*Larrea divaricata*), Chihuahuan whitethorn (*Acacia neovernicosa*), mariola (*Parthenium incanum*), and tarbush (*Flourensia cernua*). Riparian vegetation along a rocky bedrock/gravel wash includes desert willow (*Chilopsis linearis*), netleaf hackberry (*Celtis reticulata*), desert hackberry (*C. pallida*), woolly buckthorn (*Sideroxylon lanuginosa*), soap tree yucca (*Yucca elata*), Arizona walnut (*Juglans major*), and Coahuila juniper (*Juniperus coahuilensis*). The flora is diverse with 334 taxa in 62 families. The most important plants are in the Poaceae (58 taxa), Asteraceae (48), Fabaceae (24), and Malvaceae (23) in the genera *Euphorbia* (11), *Abutilon* (7), *Bouteloua* (7), *Eragrostis* (6), *Ipomoea* (6), and *Muhlenbergia* (6). Ten species are the first records for the state of Sonora, including *Chamaesaracha sordida*, *Cyphomeris gypsophiloides*, *Hybanthus verticillatus*, *Physaria fendleri*, *Quercus pungens*, *Ruellia parryi*, *Sphaeralcea polychroma*, and *Vicia ludoviciana*. Other noteworthy Sonoran records include *Bernardia myricaefolia*, *Dalea formosa*, *Phyllanthus polygonoides*, and *Vauquelinia californica* ssp. *pauciflora*, among others.

Flora de las calizas de la Sierra Anibácachi, municipio de Agua Prieta, Sonora. Se colectaron un total de 590 ejemplares de herbario (con varios duplicados) en el área de La Calera en el noreste de Sonora, en 20 salidas de campo de 2002 a 2008. Los 25 km² del área (2.5 km² colectados de forma intensa) de la Sierra Anibácachi, municipio de Agua Prieta, se localizan 11 km al sur de la frontera con Arizona (31°13'59"N 109°37'53"W, ca. 1287 m elevación). El matorral del Desierto Chihuahuense en substratos de caliza está dominado por hediondía (*Larrea divaricata*), vinorama (*Acacia neovernicosa*), hierba ceniza (*Parthenium incanum*) y *Flourensia cernua*. La vegetación ribereña en el arroyo de lecho rocoso y grava incluye: jánota (*Chilopsis linearis*), cúmero (*Celtis reticulata*), garambullo (*C. pallida*), huajuco (*Sideroxylon lanuginosa*), nogal (*Juglans major*), huata (*Juniperus coahuilensis*) y *Yucca elata*. La flora es diversa con 334 taxones en 62 familias. Las especies más numerosas pertenecen a las familias Poaceae (58 taxones), Asteraceae (48), Fabaceae (24) y Malvaceae (23) y a los géneros *Euphorbia* (11), *Abutilon* (7), *Bouteloua* (7), *Eragrostis* (6), *Ipomoea* (6) y *Muhlenbergia* (6). Diez especies son los primeros registros para Sonora, entre ellos *Chamaesaracha sordida*, *Cyphomeris gypsophiloides*, *Hybanthus verticillatus*, *Physaria fendleri*, *Quercus pungens*, *Ruellia parryi*, *Sphaeralcea polichroma* y *Vicia ludoviciana*. Otros registros importantes para Sonora incluyen *Bernardia myricaefolia*, *Dalea formosa*, *Phyllanthus polygonoides* y *Vauquelinia californica* ssp. *pauciflora*, entre otros.

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Babacomari River Riparian Protection Project. The Babacomari River is a major tributary of the San Pedro River in Santa Cruz and Cochise Counties, Arizona. This 140,000 acre catchment includes rolling grasslands on the Sonoita plain, oak woodlands in the Canelo Hills and the pine-oak forests of the northwestern Huachuca Mountains. The Babacomari River runs for 22 miles from its headwaters near Sonoita at 5000 feet elevation, eastward to join the San Pedro at Fairbanks at an elevation of 3850 feet. The US Geological Survey estimates that this important tributary contributes about 6000 acre feet of water annually to the San Pedro River system. The Arizona Dept. of Water Resources funded this 5 year study with a grant (09-164WPF) in 2009. Monitoring transects were installed in 2009 and 2010 and will be re-read each year through 2013. Objectives: Construct 2 miles of riparian boundary fence to restrict access by livestock from the Babacomari River. Install six stream riparian vegetation and geomorphic monitoring transects and six vegetation and geomorphic transects on riparian grasslands (sacaton) tributary to the Babacomari River. Analyze and summarize data annually and present that information to the participating ranch properties for use in making management decisions. Riparian monitoring stations were established in May of 2010 at three locations along the Babacomari River below the Babacomari Ranch headquarters. Riparian monitoring stations were established at three locations in June of 2010 on the Appleton-Whittell Research Ranch of the National Audubon Society. They have been re-read in June of 2011. Riparian grasslands include large bottomlands of giant sacaton (*Sporobolus Wrightii* Monro ex Scribn) on both the Babacomari Ranch (BR) and the Audubon Research Ranch (ARR). Riparian grassland monitoring stations were established in the fall of 2009, re-read in 2010 and 2011. In addition to this monitoring effort the Babacomari Ranch has begun to protect private lands along the Babacomari River by selling development rights and placing conservation easements on the land. The money largely comes from the US Army (Fort Huachuca) buffering military lands used for training and testing. The majority of lands on the Research Ranch are already protected from development.

Proyecto de protección ribereña en el río Babacomari. El río Babacomari es un afluente importante del río San Pedro en los condados de Santa Cruz y Cochise, Arizona. Esta cuenca de 56, 656 has incluye pastizales de pendiente suave en la llanura de Sonoita, encinales del área de Canelo Hills y los bosques de pino-encino del noroeste de la cordillera Huachuca. El río Babacomari recorre 35 km desde su nacimiento cerca de Sonoita a 1524 m, hacia el este donde se une al San Pedro en Fairbanks, a una altura de 1173 m. El Servicio Geológico de E.U. estima que este importante afluente aporta anualmente unos 6000 acres-pies de agua al sistema del río San Pedro. El Departamento de Recursos Hidráulicos de Arizona financió este estudio de 5 años con el proyecto (09-164WPF) en 2009. Los transectos de monitoreo se ubicaron en 2009 y 2010 y continuarán hasta el 2013. Objetivos: Cercar 3.2 km para evitar el acceso del ganado desde el río Babacomari. Seleccionar seis transectos de monitoreo de vegetación ribereña y geomorfología en el arroyo y seis transectos de vegetación y geomorfología en pastizales de zacatón ribereños tributarios del río Babacomari. Presentar un reporte con análisis de datos a los propietarios ganaderos para el manejo del área. Estaciones de monitoreo ribereñas se establecieron en mayo de 2010 en tres lugares del río Babacomari antes de la casa del rancho Babacomari. También se establecieron en tres localidades de la estación biológica Appleton-Whittell de la National Audubon Society, en junio de 2010. El monitoreo se repitió en junio de 2011. Los pastizales ribereños incluyen grandes áreas de zacatón (*Sporobolus wrightii* Monro ex Scribn), tanto en el rancho Babacomari y la propiedad Audubon. Se realizaron monitoreos de pastizales ribereños en el otoño de 2009 y se repitieron en 2010 y 2011. Además de este monitoreo, el rancho Babacomari ha empezado a proteger las tierras privadas del río Babacomari mediante la venta de derechos y la creación de servidumbres ecológicas. Los fondos provienen principalmente del ejército de E.U. (Fort Huachuca) de conservación de terrenos militares para entrenamiento y pruebas. La mayor parte del terreno de la estación biológica está protegido de la urbanización.

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A comparison of the herpetofaunas of Ranchos Los Fresnos and El Aribabi in Northern Sonora, México. To compare and contrast herpetofaunas at Ranchos Los Fresnos and El Aribabi in northern Sonora, México, we conducted herpetological surveys during 2006-2011, contacted others working in these two areas, and queried 25 museums for specimens collected at or near these ranchos. Based on this work, nine and seven amphibian, and 27 and 23 reptile species are known to occur at Ranchos El Aribabi and Los Fresnos, respectively. Significant findings include at Los Fresnos, presence of presumed Sonora tiger salamanders (*Ambystoma mavortium stebbinsi*), of which there are only three localities in México; Arizona treefrog (*Hyla wrightorum*) at several sites; and Mexican gartersnake (*Thamnophis eques*); and at El Aribabi, neotropical whipsnake (*Coluber mentovarius*), a range extension of 212 km, Tarahumara salamander (*Ambystoma rosaceum*) near the northern edge of its range, and Mexican gartersnake. Both ranchos support non-native American bullfrogs (*Lithobates catesbeianus*) and non-native fishes. Non-native crayfish (*Orconectes virilis*) are also present at Rancho Los Fresnos. In total, 46 species of amphibians and reptiles were found, 22 of which occur on both ranchos. Rancho Los Fresnos supports high grassland species not found at El Aribabi, while a number of typically Sonoran Desert, foothills thornscrub, and montane species found at El Aribabi were not encountered at Los Fresnos.

Comparación de la herpetofauna de los ranchos Los Fresnos y El Aribabi en el Norte de Sonora, México. Para comparar y contrastar las herpetofaunas de los ranchos Los Fresnos y El Aribabi en el norte de Sonora, México, realizamos un censo herpetológico de 2006 a 2011, contactamos a otros que han trabajado en estas dos áreas y consultamos 25 museos sobre especímenes recolectados en o cerca de estos ranchos. A partir de esta investigación, 9 y 7 especies de anfibios y 27 y 23 de reptiles se reportan de los ranchos El Aribabi y Los Fresnos, respectivamente. Registros importantes incluyen para Los Fresnos, la presencia de las presuntas salamandras tigre de Sonora (*Ambystoma mavortium stebbinsi*), de las cuales sólo hay tres localidades en México; Rana arborícola de Arizona (*Hyla wrightorum*) en varios sitios, y culebra del agua (*Thamnophis eques*); y en El Aribabi, culebra chirrionera neotropical (*Coluber mentovarius*), una extensión del rango de 212 km, salamandra tarahumara (*Ambystoma rosaceum*) cerca del límite norte de su distribución, y culebra del agua. Los dos ranchos tienen la rana toro introducida (*Lithobates catesbeianus*) y peces no nativos. El langostino introducido (*Orconectes virilis*) también está presentes en el rancho Los Fresnos. En total, se encontraron 46 especies de anfibios y reptiles, de las cuales 22 ocurren en ambos ranchos. El rancho Los Fresnos tiene especies de pastizales altos que no se encuentran en El Aribabi, mientras una serie de especies típicas del desierto Sonorense, matorral espinoso de piedemonte y especies de montaña que se encuentran en El Aribabi no se encontraron en Los Fresnos.

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The mustard family (Brassicaceae) of the Madrean Archipelago in Sonora, México. The Madrean Archipelago in northeastern Sonora harbors 37 species and one hybrid of mustards in 25 genera. *Lepidium*, represented by six species, is the most diverse genus. Thirteen species are non-native weeds, with several of them considered to be noxious, especially *Brassica tournefortii*. Recent fieldwork, including expeditions for the Madrean Archipelago Biodiversity Assessment (MABA) Project, has discovered several new records for Sonora and greatly expanded our knowledge of the group in this region. *Draba viridis*, a regional endemic species known only from the Sierra San José, Sonora, and the Huachuca and Santa Catalina mountains in Arizona, is of conservation concern. Three species known from the Sky Island Region of southern Arizona that should be looked for in adjacent Sonora are *Draba bifurcata*, *Draba petrophylla*, and *Pennellia tricornuta*. An additional seven species (5 native) of Brassicaceae occur in the Sierra Madre Occidental (SMO) in eastern Sonora. The center of diversity for these Brassicaceae

is in the western United States. Unlike many plant groups with tropical affinities, diversity in general declines southward from the northern Sky Islands Region in Sonora (37 taxa), although the Yécora area in the SMO is moderately diverse (23 taxa).

La familia de las mostazas (Brassicaceae) del Archipiélago Madreño en Sonora, México. El Archipiélago Madreño en el noreste de Sonora alberga 37 especies y un híbrido de mostazas en 25 géneros. *Lepidium*, representado por seis especies es el género más diverso. Trece especies son malezas introducidas y varias se consideran nocivas, especialmente *Brassica tournefortii*. En trabajo de campo reciente, entre éstas las expediciones del proyecto de Evaluación de la Biodiversidad del Archipiélago Madreño (MABA), se descubrieron varios registros nuevos para Sonora y aumentó bastante nuestro conocimiento del grupo en esta región. *Draba viridis*, una especie endémica regional conocida sólo de la Sierra San José en Sonora y las Sierras Huachuca y Santa Catalina en Arizona se considera como especie en riesgo. Tres especies conocidas de la Región de las Islas Serranas del sur de Arizona que deben buscarse en el área adyacente de Sonora son: *Draba bifurcata*, *Draba petrophylla* y *Pennellia tricornuta*. Otras siete especies (5 nativas) de Brassicaceae ocurren en la Sierra Madre Occidental (SMO) del este de Sonora. El centro de diversidad de estas especies de Brassicaceae es el occidente de Estados Unidos. A diferencia de muchos grupos de plantas con afinidades tropicales, la diversidad en general disminuye hacia el sur desde el norte de la Región de las Islas Serranas en Sonora (37 taxones); aunque el área de Yécora en la SMO tiene una diversidad moderada (23 taxones).

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Analyzing change in ciénega area with aerial photography. Ciénegas are one of the rarest and most endangered habitats in southern Arizona. Historic alteration and destruction has eliminated/reduced the extent of approximately 95 percent of ciénegas in the region. However, ciénegas are rather poorly studied and quantitative data regarding the area and location of historic and even current ciénegas is lacking. In order to quantify the current area and perimeters of ciénegas at Las Ciénegas National Conservation Area we are creating ground-truthed shapefiles with sub-meter accurate GPS units. These shapefiles will provide baseline data for informed monitoring and study of the ciénegas and will benefit many diverse parties, including hydrologists and ecologists, working from the species-level to the landscape level. The data is necessary to evaluate any future changes in the area resulting from natural processes, climate change or anthropogenic dewatering. Additionally, the shapefiles are being used to compare to 1930's Fairchild aerial photography to detect historic changes in both ciénega area and vegetation. Results and challenges are discussed.

Uso de fotografía aérea para el análisis del cambio en el área de ciénegas. Las ciénegas son uno de los hábitats más escasos y amenazados del sur de Arizona. Cambios y destrucciones en el pasado han eliminado o reducido aproximadamente 95% de ciénegas en la región. Sin embargo, las ciénegas son poco estudiadas y se carece de datos cuantitativos sobre el área y ubicación de ciénegas históricas e incluso actuales. Con el fin de medir el área actual y perímetro de ciénegas en el Área de Conservación Nacional Las Ciénegas, estamos creando shapefiles de verificación en tierra con unidades de GPS de precisión submétrica. Estos shapefiles proporcionarán información de referencia para monitoreos y estudios de mejor calidad de ciénegas y será útil a muchos investigadores, incluyendo hidrólogos y ecólogos, y estudios desde nivel de especie hasta el paisaje. Los datos son necesarios para evaluar cualquier cambio futuro en el área como resultado de procesos naturales, el cambio climático o sequía antropogénica. Los shapefiles también se están utilizados para hacer una comparación de la fotografía aérea de Fairchild de 1930 y detectar cambios históricos, tanto en área como en vegetación de la ciénega. Se presentarán resultados y dificultades.

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Species richness and avian community dynamics in the Arizona Sky Islands. The Sky Islands in southeastern Arizona contain a unique and rich avifaunal community located within diverse habitats. The avifauna within these mountains includes many Neotropical migratory species whose northern breeding range extends to these mountains along with many species typical of similar habitats throughout western North America and the continent. Understanding ecological factors that influence species richness and biological diversity of both resident and migratory species is important for conservation of this unique bird assemblage. We use a 5-year data set to evaluate avian species distribution across a diverse set of montane habitat types within the Santa Rita, Santa Catalina, Huachuca, Chiricahua, and Pinaleno Mountains. Using point-count data from spring-summer breeding seasons, we describe how avian diversity and community dynamics change through time. We use Bayesian hierarchical models to describe occupancy as a function of variables like vegetation zone and year, while accounting for variables that influence detection probability (e.g., species heterogeneity). By identifying important habitat correlates for avian species, these results help guide management decisions to minimize loss of key habitats and guide rehabilitation and restoration efforts in response to disturbance events, such as fire, in the Madrean Archipelago.

Riqueza de especies y dinámica de la comunidad de aves en las Islas Serranas de Arizona. Las Islas Serranas, del sureste de Arizona contienen una comunidad de avifauna diversa y única, localizada en diversos hábitats. La avifauna en estas montañas incluye muchas especies migratorias neotropicales cuyo límite norte de reproducción se extiende hasta estas montañas, junto con muchas especies típicas de hábitats similares del oeste norteamericano y el continente. El estudio de los factores ecológicos que influyen en la riqueza de especies y diversidad biológica tanto de especies residentes como migratorias es importante para la conservación de este ensamble único de pájaros. Utilizamos una base de datos de 5 años para evaluar la distribución de especies de aves en una asociación de diversos de tipos de hábitat en las montañas Santa Rita, Santa Catalina, Huachuca, Chiricahua, y Pinaleno. Usando datos de conteo de puntos de las temporadas de reproducción de primavera-verano, describimos cómo la diversidad y las dinámicas de la comunidad aviaria cambian con el tiempo. Usamos modelos jerárquicos Bayes-

ianos para describir la ocupación en función de variables como la zona de vegetación y año, teniendo en cuenta las variables que influyen en la probabilidad de detección (por ejemplo, la heterogeneidad de las especies). Al identificar importantes correlaciones de hábitat para especies de aves, estos resultados ayudan a tomar decisiones de manejo para minimizar la pérdida de hábitats clave y guiar los esfuerzos de rehabilitación y restauración en respuesta a eventos de perturbación, como incendios, en el Archipiélago Madreño.

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Arid-grassland mapping as a decision support tool for restoration planning and rare plant survey. We used fine-scale mapping of ecological sites and states (condition) at two locations in southern New Mexico to identify restoration priorities and effective treatment options, including grade control structures, herbicide application and prescribed burning. The Pitchfork Ranch near Silver City, NM, supports grassland-dependent species like Aplomado falcon and pronghorn and, embedded within the grassland, a rare cienega wetland. Mapping products at this site are linked to hydrological models of the watershed to better inform restoration strategies. We have installed rock structures along almost 2km of severely eroded floodplain grassland in addition to other treatments to prevent further down-cutting and soil loss, and plan to use the site as a demonstration to increase landowner engagement in restoration elsewhere in the watershed. At a second site near Hachita, NM, ecological site-state maps will support the BLM's efforts to restore grassland habitat while protecting the rare Chihuahua scurfpea (*Pediomelum pentaphyllum*), known from only three populations in southern New Mexico and Arizona. Mapping products and plot-level habitat characterization at known plant locations inform a species distribution model which will improve the efficiency of locating this ephemeral plant prior to ground-disturbing activities or herbicide treatments.

Cartografía de pastizales áridos como recurso de apoyo en los programas de restauración y estudio de plantas raras. Utilizamos cartografía a escala fina de sitios ecológicos y sus estados (condiciones) en dos localidades del sur de Nuevo México para identificar prioridades de restauración y opciones de tratamiento eficaces, incluyendo estructuras para estabilizar pendientes, aplicación de herbicidas y quemadas prescritas. El rancho Pitchfork cerca de Silver City, NM, mantiene especies de pastizales como el halcón aplomado y el berrendo, y dentro de la pradera, un humedal de ciénega. Los mapas del área están ligados a modelos hidrológicos de la cuenca para ilustrar mejor las estrategias de restauración. Hemos instalado gaviones en casi 2 km del pastizal de la planicie aluvial severamente erosionado, además de otros tratamientos para prevenir más pérdida de suelo, y planeamos usar el lugar como sitio demostrativo para aumentar la participación de propietarios en la restauración en otras partes de la cuenca. En otro sitio cerca de Hachita, NM, mapas ecológicos del área le serán útiles al BLM para restaurar el hábitat de pastizales, al mismo tiempo que se protege la planta escasa "contrahierba de Chihuahua" (*Pediomelum pentaphyllum*), conocida sólo de tres poblaciones en el sur de Nuevo México y Arizona. Los mapas y la caracterización del hábitat a nivel de parcela de las localidades conocidas actualizan la distribución de la especie y mejoran la eficiencia de la localización de esta planta efímera antes de actividades perturbadoras del suelo o tratamientos herbicidas.

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Vascular plants of El Aribabi Conservation Ranch: plant diversity of a private natural protected area in northern Sonora, México. In northeastern Sonora, isolated mountains or sky islands are recognized for their high biodiversity, sustaining vegetal communities like desert scrubs, natural grasslands, oak woodlands and pine-oak forests; within this region (30°51'14.59"N, 110°41'11.91"W and 30°48'29.82"N, 110°32'5.59"W) is located El Aribabi Conservation Ranch. The flora of the ranch is based in more than 1000 herbarium specimens collected by the Universidad de Sonora herbarium (USON) and with observations records from the MABA (Madrean Archipelago Biodiversity Assessment) database. The flora accounts 454 vascular plants belonging to 87 families and 279 genera. Families with the greatest number of species are Asteraceae (65), Poaceae (41), Fabaceae (37), Euphorbiaceae (18), Malvaceae (13), Cactaceae (11) and 9 ferns. Only two species of the flora are nominated with risk category by Norma Oficial Mexicana NOM-059. Non-native plants (27) represent 6 % of the flora and only 6 are invasive. This work was carried out with financial support from the CONABIO and is important for its contribution to knowledge of the flora of the northern border, in addition, the ranch was recently declared by the CONANP as a private protected natural area.

Plantas vasculares del Rancho El Aribabi: diversidad vegetal de un área natural protegida privada en el norte de Sonora, México. En la región noreste del Estado de Sonora, montañas aisladas denominadas "islas serranas" y caracterizadas por una alta biodiversidad, sostienen comunidades de matorrales xerófilos, pastizales naturales, encinares y bosques de pino-encino; en esta región se localiza el rancho El Aribabi, con coordenadas 30°51'14.59"N, 110°41'11.91"W y 30°48'29.82"N, 110°32'5.59"W. La flora del rancho está respaldada por más de 1000 ejemplares depositados en el herbario USON y observaciones registradas en la base de datos del proyecto MABA (Madrean Archipelago Biodiversity Assessment). Se contabilizaron un total de 454 especies de plantas vasculares pertenecientes a 87 familias y 279 géneros. Las familias con mayor número de especies son Asteraceae (65), Poaceae (41), Fabaceae (37), Euphorbiaceae (18), Malvaceae (13), Cactaceae (11) y 9 helechos. Sólo dos especies de la flora están nominadas con categoría de riesgo por la Norma Oficial Mexicana NOM-059. Las especies no nativas (27) representan el 6 % de la flora y sólo 6 son invasoras. Este trabajo se llevó a cabo con el apoyo financiero de la CONABIO y es importante por su contribución al conocimiento de la flora de la frontera norte; además, el rancho fue declarado recientemente por la CONANP como área natural protegida privada.

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Restoration of Lesser long-nosed bat forage resource: a group effort. In 2007, the construction of the international border fence within Coronado National Memorial (CORO) resulted in the loss of an estimated 3700 Palmer's agave (*Agave palmeri*) plants, which are the primary food source in Southeastern Arizona of the endangered Lesser long-nosed bat (*Leptonycteris curasoae yerbabuena*). A comprehensive mitigation effort was necessary, thus, CORO initiated a collaborative effort between the National Park Service (NPS), US Fish and Wildlife Service, and the Department of Homeland Security to restore lost agaves. In 2009, CORO contracted with the Natural Resources Conservation Service, Plant Materials Center in Tucson, Arizona to grow 4500 agave over three years. Each year, beginning in 2010, CORO hosts an annual agave planting event, involving a coordinated effort between the public and staff from CORO, other NPS units, and other land management agencies. In 2011, more than 130 volunteers and staff planted 1100 agaves during the one day event. Thus, there are two measures of success for this project: (1) the replacement of 3700 lost agaves; and (2) the sense of community, wholesome outdoor experience, and feeling of ownership afforded to all attendees. CORO will host the final annual agave planting event during the summer of 2012.

Restauración de recursos forrajeros del murciélago 'magueyero chico': un esfuerzo grupal. En 2007, la construcción del muro fronterizo en el Memorial Nacional de Coronado (CORO) ocasionó la pérdida de cerca de 3700 plantas de lechuguilla (*Agave palmeri*), que en el sureste de Arizona son la fuente primaria de alimento del murciélago magueyero chico (*Leptonycteris curasoae yerbabuena*) en peligro de extinción. Se necesitaba un trabajo intensivo de mitigación, por lo que CORO inició un proyecto colaborativo entre el Servicio de Parques Nacionales (NPS), Fish and Wildlife Service de EU y el Departamento de Seguridad Nacional para reemplazar las lechuguillas perdidas. En 2009, CORO firmó un contrato con el Servicio de Conservación de Recursos Naturales, Centro de Plantas en Tucson, Arizona para propagar 4500 agaves en tres años. Cada año, a partir de 2010, CORO organiza un evento anual de plantación de lechuguillas, que implica un esfuerzo coordinado entre el sector público y el personal de CORO, otras unidades del servicio de parques nacionales, y otras agencias de manejo de recursos naturales. En 2011, más de 130 voluntarios y personal plantaron 1100 agaves durante el evento de un día. Así, hay dos medidas de éxito para este proyecto: (1) el reemplazamiento de 3700 lechuguillas perdidas, y (2) el sentido de comunidad, la experiencia saludable al aire libre, y el sentimiento de propiedad que se ofrece a los asistentes. CORO tendrá el último evento anual de plantación de agaves durante el verano de 2012.

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The sand dune of Ruby, an anthropogenically created biodiversity hotspot for wasps and their velvet ant parasitoids. Ruby, Arizona, a historically important mining town in Southern Arizona that deep mined millions of tons of ore, the crushed remains of which after mineral extraction were piled into a large sand dune. The dune became an ideal nesting habitat for a variety of insects, plus blocked the valley, thereby generating two lakes. Today the ghost town is an important biodiversity refuge. A large number of species of sand wasps, including cicada killers, have colonized the dune area, sometimes with world-record-breaking populations. Concomitant with the wasp colonizations were migrations of a variety of species of velvet ant (Hymenoptera: Mutillidae) parasitoids of the wasps. Environmental resource partitioning among the wasps and their parasitoids in this newly created habitat will be presented and the importance of preservation of various types of land will be discussed. I thank Howard Frederick of Wildlife World Wide, Cortaro, AZ, for facilitating this study at Ruby and encouraging the research.

La duna de arena de Ruby, un centro de biodiversidad de avispas y sus parásitos las comadritas, creado antropogénicamente. Ruby, Arizona, es un pueblo minero de importancia histórica en el sur de Arizona, que minó millones de toneladas de mineral subterráneo, donde los jales, después de la extracción de minerales, se apilaban en una gran duna de arena. La duna se convirtió en un hábitat ideal para la anidación de una gran variedad de insectos, además de bloquear el valle, lo que generó dos lagos. Actualmente el pueblo fantasma es un refugio importante de biodiversidad. Un gran número de especies de avispas de arena, incluidas las asesinas de chicharras, ha colonizado la duna, a veces con poblaciones de récord mundial. Simultáneamente con las colonizaciones de avispas ocurrieron las migraciones de una gran variedad de especies de 'comadritas' (Hymenoptera: Mutillidae) parásitos de las avispas. Se presentará la división de los recursos del medio ambiente entre las avispas y sus parásitos en este hábitat de nueva creación y se abordará la importancia de la preservación de los distintos tipos de terreno. Agradezco a Howard Frederick de Wildlife World Wide, Cortaro, AZ por facilitar este estudio en Ruby y fomentar la investigación.

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Camera trapping in the Cajon Bonito Watershed: a synthesis. The Cuenca Los Ojos Foundation, with extensive properties in the northeast corner of the state of Sonora, has conducted a camera trapping program in Cajon Bonito for two years. The Cajon Bonito is a major interior drainage and perennial stream in the Sierra San Luis range, flowing north then west into the Rio San Bernardino. Through long-term restoration and water conservation efforts of Cuenca Los Ojos Foundation, Cajon Bonito and surrounding areas now support a vibrant array of native plant and animal species including the rare ocelot and the second largest population of black bear in Mexico. Our camera trapping project has provided consistent monitoring and quantification of the wildlife found here, allowing for identification of most mammal species present including endangered species in close proximity to the US border. In addition to providing information on presence of species, camera trapping provides important information on local populations of prey species, with spikes or drops in animal populations as signs of possible disease or

poaching. Recently we have incorporated a data collection and processing system developed by Jim Sanderson and Jack Childs that has enabled interesting comparisons to other study sites in the US and Mexico with the Cajon Bonito site.

Síntesis del trabajo con cámaras trampa en la Cuenca de Cajón Bonito. La Fundación Cuenca Los Ojos, con extensas propiedades en la esquina noreste del estado de Sonora, ha llevado a cabo un programa de trapeo fotográfico en Cajón Bonito por dos años. El Cajón Bonito es un drenaje interior importante de corriente perenne en la Sierra San Luis, que fluye al norte y luego al oeste hacia el arroyo San Bernardino. Mediante trabajos a largo plazo de restauración y conservación del agua de la Fundación Cuenca Los Ojos, el Cajón Bonito y zonas adyacentes ahora mantienen una gran diversidad de especies de plantas y animales nativos incluyendo el raro ocelote y la segunda población más grande de oso negro en México. Nuestro proyecto con cámaras trampa ha mantenido un monitoreo constante y censo de la fauna silvestre que se encuentra aquí, lo que permite la identificación de la mayoría de especies de mamíferos presentes, incluyendo especies amenazadas en las proximidades de la frontera con E.U. Además de proporcionar información sobre la presencia de especies, el trapeo fotográfico proporciona información importante sobre las poblaciones de especies presa locales, con picos o caídas en las poblaciones de animales como signos de posibles enfermedades o de caza furtiva. Recientemente Jim Sanderson y Jack Childs diseñaron una base de datos, que ha permitido hacer interesantes comparaciones entre sitios de estudio en E.U. y México con el Cajón Bonito.

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Recent records of Western Yellow Bats (*Lasiurus xanthinus*) in Arizona. Western yellow bats are insectivorous tree-roosting bats, first recorded in Arizona in 1960. Although found within or near non-native *Washingtonia* palm trees in Arizona, the bats are otherwise obligate canyon or riparian dwellers at the northern end of their distribution in southeast Arizona. Hoffmeister's (1986) 'Mammals of Arizona' lists only seven localities with potential information recorded from only 18 individuals. Current status of *Lasiurus xanthinus* is 'priority' or 'sensitive' species by interest groups, federal, state, and county government (e.g., in Pima County Sonoran Desert Conservation Plan). From 2002-2008 we captured six *L. xanthinus* at three new non-urban localities. Arizona Game and Fish HDMS database shows six other new localities; all new localities are unpublished. Rarely caught in biological surveys, this species is more abundant than expected among bats sent to Arizona State Health Department in Tucson for rabies testing. Between 2000-2007 we identified >40 western yellow bats from five sites (including three new localities). These yellow bats were taken each month from April through November, with equal numbers of males and females, and adults and young. Clearly this is another example of a southern species moving northward.

Registros recientes de murciélagos amarillos occidentales (*Lasiurus xanthinus*) en Arizona. Los murciélagos amarillos occidentales son murciélagos insectívoros que usan los árboles como refugio; se registraron por primera vez en Arizona en 1960. Aunque se les encuentra en o cerca de palmeras (*Washingtonia* introducidas en Arizona), los murciélagos son habitantes ribereños o asociados a cañones en el extremo norte de su distribución en el sureste de Arizona. 'Mamíferos de Arizona' de Hoffmeister (1986) enlista tan sólo siete localidades con información potencial registrada de sólo 18 individuos. El estatus de riesgo de *Lasiurus xanthinus* en E.U. es similar a 'especie rara' o 'sujeta a protección especial' para el gobierno federal, estatal y de condado (por ejemplo, el Plan de Conservación del Desierto Sonorense del Condado de Pima). De 2002 a 2008 se capturaron seis *L. xanthinus* en tres nuevas localidades no urbanas. La base de datos HDMS de Arizona Game and Fish incluye otras seis localidades nuevas; todas las localidades nuevas no están publicadas. Rara vez atrapada en investigaciones biológicas, esta especie es más abundante de lo esperado entre murciélagos enviados al Departamento de Salud del Estado de Arizona en Tucson para pruebas de rabia. Entre 2000-2007 se identificaron >40 murciélagos amarillos occidentales en cinco sitios (incluyendo tres nuevas localidades). Estos murciélagos amarillos fueron colectados cada mes desde abril hasta noviembre, con igual número de machos y hembras, y adultos y jóvenes. Es evidente que este es otro ejemplo de una especie del sur moviéndose hacia el norte.

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Prairie dogs and cattle interactions: Shifting from competition to a grazing association. Since the mid nineteenth century, prairie dogs were considered a pest by the inhabitants of rural communities through their historical range mainly because they were presumed to compete with cattle for available forage resources; a belief reinforced by the eradication campaigns implemented from the early 1900's to date. Nowadays, prairie dogs occupy less than 2% of their historical distribution, and vertebrate associated species are affected, like black-footed ferret –which is nearly extinct. Despite the intensity of the eradication campaigns, no scientific data support the competition-only interaction claims, it's based only in social perceptions. This research addresses the question if prairie dogs and cattle interactions could be mutualistic, similar to those observed between American bison and prairie dogs. Beef cattle (*Bos taurus*) habitat selection in relation with prairie dog presence was measured on a short grass ecosystem within the Janos Biosphere Reserve. Analyses of cattle movements show a direct preference for prairie dog colonies, with a strong preference to forage in the margins. From these observations we conclude that cattle-prairie dog interactions resemble bison-prairie dog grazing associations, opening a new discussion about future management strategies for the North American grasslands.

Perritos de la pradera e interacciones con el ganado: De la competencia a una asociación de pastoreo. Desde mediados del siglo XIX, los perritos de la pradera fueron considerados una plaga por los habitantes de las comunidades rurales en su área de distribución histórica, principalmente porque se presumía que competían con el ganado por recursos forrajeros. Esta creencia fue reforzada por las campañas de erradicación implementadas desde principios de 1900 hasta la fecha. Actualmente, los perritos de la pradera ocupan menos del 2% de su distribución histórica, y especies de vertebrados asociados se ven afectadas, como el hurón de patas negras, que está casi extinto. A pesar de la intensidad de las campañas de erradicación, no hay datos científicos que apoyen las pretensiones de interacción únicamente competitiva, se basan solamente en percepciones sociales. Esta investigación aborda la cuestión de si los perros de las praderas y las interacciones con ganado pudiesen ser mutualistas, similares a las observadas entre el bison americano y los perros de la pradera. La selección de hábitat del ganado vacuno (*Bos taurus*) en relación con la presencia de perros de la pradera se midió en un ecosistema de pastos cortos dentro de la Reserva de la Biosfera de Janos. Los análisis del movimientos de ganado muestran una preferencia directa por colonias de perritos de la pradera, con una fuerte preferencia por el forraje en los márgenes. A partir de estas observaciones se concluye que las interacciones entre ganado y perritos de la pradera, se parecen a las asociaciones de pastoreo entre bisontes y perritos de la pradera, lo que abre una nueva discusión sobre las futuras estrategias de manejo de praderas de América del Norte.

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Moving from adaptive management to climate adaptation: experiences from agency staff and stakeholders at the Las Ciénegas National Conservation Area. Advocates of climate adaptation often cite adaptive management as a crucial tool for helping natural systems cope with the impacts of climate change. Yet this tool is challenging to implement. Las Ciénegas has pursued adaptive management for some 15 years, and is now sharing lessons on what has worked well and what has not. The site's approach allows BLM and regional stakeholders to monitor and evaluate ecosystem changes, and adjust management actions based on what they learn. This process builds the knowledge, flexibility and community support needed to manage lands in a changing climate. Yet the partnership has recognized that in some cases, making adjustments to existing activities may not be enough to buffer the watersheds from effects of rapid change. BLM and partners are examining how to further incorporate climate adaptation by modifying monitoring protocols; implementing no regrets actions; and identifying areas where typical actions may be ineffective or even counterproductive. Current no-regrets actions include boosting the capacity of floodplains to capture sediment and slow release of runoff water. Scenario planning activities are now helping the group identify what might need to be done quite differently depending on how climate shifts and ecosystems respond, and on how agency resources change.

Del manejo adaptativo a la adaptación al clima: experiencias del personal de agencia y sectores interesados del Área de Conservación Nacional Las Ciénegas. Defensores de la adaptación al clima citan frecuentemente el manejo adaptativo como requisito para ayudar a los sistemas naturales a superar los impactos del cambio climático. Pero este requerimiento es difícil de implementar. Las Ciénegas ha efectuado el manejo adaptativo por unos 15 años, y ahora comparte experiencias de lo que ha funcionado y lo que no. El enfoque del sitio permite a la Oficina de Administración de Tierras (BLM por sus siglas en inglés) y los sectores regionales interesados monitorear y evaluar los cambios del ecosistema y ajustar el manejo según lo aprendido. Este proceso aumenta el conocimiento, la flexibilidad y el apoyo de la comunidad necesario para el manejo de recursos naturales en un clima cambiante. Pero la asociación ha reconocido que en algunos casos, el hacer cambios en las actividades actuales puede ser insuficiente para amortiguar los efectos del cambio rápido. BLM y socios están analizando cómo incorporar aún más el cambio climático al modificar los protocolos del monitoreo; implementar acciones sin remordimientos; e identificar las áreas donde las acciones típicas son inefectivas o incluso contraproducentes. Acciones sin remordimientos incluyen aumentar la capacidad de las planicies aluviales de capturar el sedimento y disminuir el escape de escorrentía. El programar para escenarios está ayudando al grupo a identificar que se necesita modificar dependiendo de como cambia el clima y de como responden los ecosistemas, y como cambian los recursos de la agencia.

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Aridland spring ciénegas: Rare southwestern habitats for endangered plants. Ciénega refugia for rare plants are medium to low elevation wet meadows created by stable springs and seeps in arid regions. A comprehensive inventory of southwestern ciénegas has not been completed; however, these habitats are clearly rare, diminishing in extent, or already eliminated. Groundwater depletion, erosion, conversion to agriculture or aquaculture, abusive grazing, and exotic weeds threaten most remaining ciénega habitats and the plants and animals in them. Several southwestern plant species are confined to these habitats, making aridland spring ciénegas distinct from other riverine or lentic wetlands in the region. Some ciénega plants have widespread distributions, but since their habitat is rare these plants are also rare and, in some cases, endangered.

Ciénegas de aguajes en zonas áridas: hábitats escasos para especies en peligro en el Suroeste Norteamericano. Las ciénegas son refugio para especies de plantas escasas y praderas húmedas de baja elevación creadas por manantiales e infiltraciones estables en regiones áridas. No se ha hecho un inventario completo de las ciénegas del suroeste; sin embargo es evidente que estos hábitats son escasos, y su extensión está disminuyendo o se ha eliminado. La disminución de los mantos acuíferos, erosión, cambio de uso de suelo hacia agricultura o acuicultura, sobrepastoreo, y especies invasoras amenazan la mayoría de las ciénegas que quedan, así como su flora y fauna. Varias especies de plantas del suroeste están restringidas a estos hábitats, distinguiendo a las ciénegas de zonas áridas de otros humedales ribereños o lenticos en esta región. Algunas plantas de ciénegas tienen una amplia distribución, sin embargo como sus hábitats son escasos las plantas también son escasas, y en muchos casos en peligro de extinción.

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Modeling current and future suitable habitat for a seedling-attacking bark beetle and its pine hosts in the Madrean Archipelago. *Dendroctonus rhizophagus* is a seedling-attacking bark beetle that occurs on pines in the Sierra Huachinera and may broadly impact pine establishment elsewhere in the Madrean Archipelago. Little is known regarding habitat requirements of *D. rhizophagus* and this complicates monitoring. We used known occurrence records to develop contemporary climate-based models to describe areas of suitable habitat for *D. rhizophagus* and six of its *Pinus* hosts throughout the Archipelago. These models were also projected to four predicted climate scenarios for the period 2040-2069. More than 2400 km² of suitable habitat for both *D. rhizophagus* and at least one host taxon are predicted to currently occur in the Archipelago north and west of known insect occurrences. The area predicted to be suitable for *D. rhizophagus* declines under two of four future climate scenarios and increases in the other two scenarios. Suitable habitat for *P. leiophylla* was predicted to increase under all future climate scenarios. Area of predicted suitable habitat generally decreases for *P. engelmannii* and *P. strobiformis* in all scenarios. Many instances were observed of unprecedented habitats for certain *Pinus* taxa under future climate scenarios. This suggests opportunities for assisted migration to maintain functioning forest ecosystems.

Modelado de hábitats actuales y futuros del descortezador de plántulas de pino y sus hospederos en el Archipiélago Madreño. El descortezador *Dendroctonus rhizophagus* ataca plántulas de pino en la Sierra Huachinera y puede afectar el establecimiento de pinos a lo largo del Archipiélago Madreño. Se conoce poco sobre el requerimiento de hábitat de *D. rhizophagus* por lo tanto se complica su monitoreo. Empleamos registros de incidencia para desarrollar un modelo basado en clima contemporáneo para describir los hábitats adecuados para *D. rhizophagus* y seis *Pinus* hospederos a lo largo y ancho del Archipiélago. Estos modelos fueron proyectados para predecir 4 escenarios climáticos para el periodo 2040-2069. Más de 2400 km² de hábitat adecuado tanto para *D. rhizophagus* y por lo menos un taxón hospedero se predice que actualmente se distribuye al norte y oeste de la localidad conocida del insecto. El área pronosticada de distribución de *D. rhizophagus* disminuye en dos de los cuatro escenarios de cambio climático y aumenta en los otros dos. Se predice que la distribución de *P. leiophylla* aumentará según los cuatro escenarios de cambio climático. En general el hábitat de *P. engelmannii* y *P. strobiformis* disminuye en todos los escenarios. En varios casos se observaron hábitats sin precedentes para ciertos taxones de *Pinus* bajo futuras condiciones de cambio climático. Esto sugiere oportunidades para migración asistida para mantener el funcionamiento del ecosistema de bosques.

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Long-term hydrological and geomorphological monitoring, Gila River, New Mexico. Persistence of native fishes and low richness and abundance of nonnative fishes in the Cliff-Gila Valley reach is partially attributable to maintenance of a natural flow regime and thus quantity and quality of aquatic habitats. Mesohabitats found within and near the river are formed by the dynamic interactions among channel form, vegetation, and flooding over time. Frequent, smaller floods play a crucial role in re-wetting the floodplain, increasing alluvial groundwater levels, and sustaining backwater wetland zones. Larger floods reconfigure extensive lengths of the active and overflow channel zones, backwaters, and floodplains. The purpose of this study is to describe channel, floodplain, and terrace morphology; floodplain surface deposits and channel bed material; and vegetation and mesohabitat classifications in the Cliff-Gila Valley. Hourly alluvial groundwater elevations on selected transects and surface flow stage provides a means of evaluating interactions between water availability and habitat creation and persistence. Long-term study results will improve our understanding of how the flow regime of southwestern rivers—including both moderate and large flood events—create and sustain a diversity of river-associated habitats, including in-channel fish habitat, wetland zones, and riparian grasslands and tree canopy.

Monitoreo a largo plazo de la geomorfología e hidrología del río Gila, Nuevo México. La persistencia de peces nativos y la poca abundancia de peces exóticos en el tramo del río en el valle de Cliff-Gila se debe en parte a que mantiene el caudal natural y por consiguiente la calidad y cantidad de hábitats acuáticos. Las interacciones dinámicas entre la vegetación, las inundaciones y las formas que toma el cauce, con el tiempo crean los hábitats húmedos del río y sus alrededores. Las inundaciones menores y frecuentes son decisivas para regar los terrenos aluviales, aumentar los niveles aluviales del acuífero y sostener las zonas de humedales del remanso. Las inundaciones grandes modifican largos tramos del cauce activo y de las zonas de desbordamiento, remanso y terrenos aluviales. El propósito de este estudio es describir la morfología del cauce, la zona de inundación y las terrazas fluviales; sedimentos de la zona de inundación y caracterización de los materiales del lecho del río; y describir la vegetación y el hábitat húmedo del valle de Cliff-Gila. El nivel del acuífero aluvial por hora en transectos seleccionados y el volumen de la superficie ayudan a evaluar las interacciones del agua disponible y la creación del hábitat y su persistencia. Los resultados de estudios a largo plazo mejorarán nuestro conocimiento de como el régimen fluvial de los ríos del suroeste de E.U. (caudales grandes o moderados) crean y sostienen una diversidad de hábitats asociados al río: hábitats para peces, humedales, pastizales ribereños y el dosel de los árboles.

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Monitoring and conservation efforts along the Santa Cruz River in Sonora, Mexico. The Santa Cruz River basin is very important economically, ecologically, and socially as the primary source of drinking water for the border cities of Nogales, Sonora, Mexico and Nogales, Arizona,

United States, referred to as “Ambos Nogales”. In recent decades, rapid population growth and man’s desire to satisfy their basic needs, have led to changes in the surrounding environment, such as overexploitation of the aquifers and loss of biodiversity of flora and fauna present in these water bodies. Aware of the need for information and knowledge on the main channel of the Santa Cruz River, monitoring was conducted on surface water quality, flora, and vegetation. Research results from various periods over the past 15 years will be presented.

Esfuerzos de monitoreo y conservación del río Santa Cruz en Sonora, México. La cuenca del río Santa Cruz (RSC) representa una gran importancia económica, ecológica y social por ser la principal fuente de abastecimiento de agua potable para las ciudades fronterizas de Nogales Sonora, México y de Nogales Arizona, Estados Unidos, referidas como “Ambos Nogales”. En las últimas décadas, el acelerado crecimiento poblacional y el deseo del hombre por satisfacer sus necesidades primordiales, han provocado cambios en el ambiente que lo rodea, repercutiendo en la sobreexplotación de los mantos acuíferos y en la pérdida de la biodiversidad de la flora y fauna presente en esos cuerpos de agua. Consientes de la necesidad de obtener información y conocimiento sobre el cauce principal del RSC se realizaron esfuerzos de monitoreo sobre calidad del agua superficial y flora y vegetación. Se presentarán resultados de investigación obtenidos en varios períodos durante 15 años.

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Identification of suitable areas for reintroduction of bison (*Bison bison*) in Chihuahua, Mexico. Bison (*Bison bison*) once ranged from Alaska to Northern Mexico, but between 1830 and 1880 were nearly driven to extinction, and with it, their ecological role in the North American grasslands was lost. Efforts are underway in Canada, the United States, and more recently in Mexico, to recover the ecological role of the bison. Using data from aerial surveys of the only free ranging bison herd in Mexico (which moves between Janos, Chihuahua and Hidalgo county, New Mexico) and predictive models (GARP and MAXENT), we identified an area suitable for bison within the Janos Biosphere Reserve in Chihuahua. Bison from Wind Cave National Park in South Dakota were translocated there in order to form a breeding herd for the production of bison for reintroduction in other suitable sites within the former range of the species, as part of both grassland and bison conservation efforts.

Identificación de áreas propicias para la reintroducción del bisonte (*Bison bison*) en Chihuahua, México. La distribución histórica del bisonte (*Bison bison*) se extendía desde Alaska hasta el norte de México, pero de 1830 a 1880 casi se extinguió y perdió su papel ecológico en los pastizales de Norteamérica. Se está trabajando tanto en Canadá, Estados Unidos y recientemente en México para recuperar el papel ecológico del bisonte. Utilizando datos de monitoreos aéreos de la única manada libre en México (que se mueve en la zona fronteriza entre Janos, Chihuahua y el condado de Hidalgo, Nuevo México) y modelos predictivos (GARP y MAXENT) se identificó un área propicia para bisonte dentro de la Reserva de la Biósfera Janos, en Chihuahua. Se trasladó a esta zona un grupo de bisontes procedentes de Wind Cave National Park, en Dakota del Sur, con el propósito de criar un grupo reproductor para posteriormente introducir más individuos a otras áreas apropiadas dentro de su distribución histórica; en un esfuerzo de conservación tanto del bisonte como de los pastizales.

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The role of precipitation in the distribution of the saguaro cactus at its upper elevation limit in Saguaro National Park. This presentation summarizes the results from a study of the saguaro population in its upper elevation range at Saguaro National Park from 3,500 to 5,500 feet. PRISM data indicates that the 30-year average annual precipitation for this elevation zone ranges from 400 to 600 mm, but declines of 10 percent are predicted by the end of the century. Using logistic regression, we model saguaro presence with data from 120 (0.25 ha) plots located at these elevations. From predictive variables of elevation, slope, fire history, solar insolation, and 30-year average annual precipitation this model predicts 70 percent of the variation in current saguaro presence at these elevations. The model indicates that when altering annual precipitation to reflect projected declines by the end of the century, these reductions in precipitation will have detrimental effects.

Efecto de la precipitación en la distribución de sahuaros en su límite de distribución más alto en el área protegida Saguaro National Park. Se presentan los resultados de un estudio de la población de sahuaro en su límite de distribución más alto, 1066 a 1676 m, en Saguaro National Park. La información de PRISM indica que la precipitación media anual en un periodo de 30 años para esta elevación varía de 400 a 600 mm, pero se estima una disminución del 10 % a finales del siglo. Usando regresión logística, se modeló la presencia de sahuaro en 120(0.25 ha.) cuadrantes localizados en esta elevación. Con variables predictivas de elevación, pendiente, historia de incendios, radiación solar, precipitación media anual de 30 años, este modelo predice 70 % de variación en la presencia de sahuaro a esta elevación. El modelo indica que al alterar la precipitación anual, para reflejar la disminución estimada para finales de siglo, esta reducción en lluvias tendrá efectos negativos.

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Calibrating our progress towards recovery of amphibian populations: an area-based approach and occupancy modeling. Like many amphibian species worldwide, the Chiricahua leopard frog (*Rana chiricahuensis*) experienced a dramatic, range wide decline during the past three decades and was listed under the Endangered Species Act (ESA) as threatened in 2002. A species recovery plan was finalized in 2007

that included four recovery criteria that, when reached, will have: 1) established sufficient populations and metapopulations, 2) managed the necessary aquatic breeding habitats, 3) managed important dispersal corridors, and 4) reduced threats so that the Chiricahua leopard frog no longer needs the protection of the ESA. Although great progress has been made since federal listing, progress on recovery criterion 1 has been hampered by 1) the dearth of suitably configured landscapes that could “host” candidate metapopulations and 2) the difficulty of establishing and monitoring stable and viable metapopulations given the limited human and financial resources available. I develop a conceptual area-based approach to calibrate progress toward recovery that is applicable to the Chiricahua leopard frog that utilizes occupancy modeling to gauge progress in establishing, managing, and monitoring viable metapopulations. This approach is easier to design and implement, makes fewer assumptions, and is less biased than the current “strict metapopulation” approach and is applicable to other patchily distributed amphibians.

Medición del progreso en la recuperación de poblaciones de anfibios: enfoque basado en área y modelado de límites de ocupación. La rana de Chiricahua (*Rana chiricahuensis*) como muchos anfibios del mundo, durante las últimas tres décadas, sufrió una disminución drástica de su población, por lo que en 2002 se catalogó como especie amenazada en la Ley de Especies en Peligro de Extinción de E.U. (ESA, siglas en inglés). Así, en 2007 se terminó un programa de acción para la conservación de la especie con cuatro metas a lograr 1) establecimiento de poblaciones y metapoblaciones, 2) manejo de hábitats acuáticos para su reproducción, 3) manejo de corredores ecológicos para su dispersión, 4) reducción de amenazas de tal forma que la rana de Chiricahua salga de la lista de ESA. A pesar del progreso obtenido desde que se encuentra en la lista ESA, el progreso de recuperación del criterio 1 se ha visto entorpecido por 1) la escasez de paisajes adecuados para facilitar metapoblaciones y 2) la dificultad de establecer y monitorear metapoblaciones ya que existe un limitado recurso humano y financiero. Desarrollé un enfoque conceptual basado en área para medir el progreso de recuperación que se puede aplicar a la rana de Chiricahua y emplea un modelado de ocupación de espacio para medir el progreso de establecimiento, manejo, y monitoreo de metapoblaciones viables. Este enfoque es más fácil de diseñar e implementar, requiere menos suposiciones, y tiene menos sesgo que el modelo actual denominado de “metapoblaciones estrictas”, y se puede aplicar a otros anfibios con distribución fragmentada.

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Factors leading to landscape-scale wildfires on the Coronado National Forest in 2011, with a summary of the affected areas. The Coronado National Forest experienced a record fire season, as far as fire size, in 2011 with over 300,000 acres impacted by wildfire. Several factors came into alignment that ultimately led to the landscape-scale fire events that affected not only the “Sky Islands” of the Coronado but adjacent land ownerships as well. The combination of moisture stressed vegetation, seasonal weather events, topography, and the frequent occurrence of ignitions influenced the scale and severity of the fires across the southern half of the Coronado. The Horseshoe 2 fire covered 222, 954 acres, in the Chiricahua Ecosystem Management Area (EMA). Fires on the western portion of the Coronado impacted over 92,000 acres on the Tumacacori, Huachuca, and Santa Rita EMA's. A considerable amount of land was affected by the fires of 2011. However, variable levels of soil burn severity occurred creating a “mosaic” of burned and unburned areas across the landscape. Although some areas require rehabilitation, other areas benefited from the wildfires creating favorable conditions that managers have the opportunity to maintain into the future. This presentation will provide an overview of the factors that “lined up” to provide the recipe for one of the largest wildfire seasons in Coronado National Forest history and the impacts of the fires on the landscape.

Factores causantes de incendios forestales a escala de paisaje en el Bosque Nacional de Coronado en 2011, con un resumen de las zonas afectadas. El Bosque Nacional de Coronado tuvo una temporada de incendios récord, en lo que a tamaño se refiere, en 2011, con más de 122.000 hectáreas afectadas por incendios forestales. Varias causas coincidieron y finalmente llevaron a incendios del paisaje que afectaron no sólo a las “Islas Serranas” del Coronado, sino también terrenos adyacentes privados. La combinación de vegetación estresada por la sequía, eventos climáticos estacionales, topografía, y la ocurrencia frecuente de igniciones influyó en la magnitud y gravedad de los incendios de la mitad sur del Coronado. El incendio La Herradura 2 cubrió 90 226 hectáreas en el Área de Manejo de Ecosistemas del Chiricahua (EMA). Los incendios en la parte occidental del Coronado impactaron más de 37 231 hectáreas en Tumacacori, Huachuca y Santa Rita del EMA. Un área considerable se vio afectada por los incendios de 2011. Sin embargo, se registraron variaciones en la severidad del suelo quemado, creando un “mosaico” de áreas quemadas y sin quemar. Aunque algunas áreas necesitan restauración, otras se beneficiaron de los incendios, creando condiciones favorables que los encargados de manejo pueden mantener. Presentamos un resumen de los factores presentes para crear la receta de una de las mayores temporadas de incendios en la historia del Bosque Nacional de Coronado y sus impactos.

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Linkages between stream hydrology, vegetation, and soil arthropods in the semi-arid highlands ecoregion of Arizona. In many streams of the Huachuca Mountains of southern Arizona, the surface flow is ephemeral or intermittent. Despite the lack of flow permanence, drainages there support highly diverse ecosystems. A better understanding of the processes that support such diversity might allow for more informed decision-making and management practices. The following questions were asked to increase our knowledge about the processes controlling species diversity: 1) Does an increase in flow permanence correlate to increased species richness for ground-dwelling arthropods and the riparian plant community? 2) Is placement within a stream network a controlling factor for species richness? Preliminary results of this multi-year study indicate that high water availability in canyons, present as surface and sub-surface flows, sustains high richness and abundance of woody plant species with large canopies; this, in turn, limits the number of herbaceous species due to shading and leaf litter. Ground-dwelling arthro-

pods, however, reach their greatest diversity in these dense riparian forests. The water-limited foothills streams and lower canyon sections have more open canopies, but support a larger number of herbaceous species. Each stream type supports different (but overlapping) communities of arthropods and plants, with the combination of different stream types thus collectively supporting high diversity.

Vínculos entre hidrología de arroyos, vegetación y artrópodos del suelo en la ecorregión del altiplano semiárido de Arizona. En muchos arroyos de las montañas Huachuca del sur de Arizona, la corriente superficial es efímera o intermitente. A pesar de la falta de corrientes continuas, los drenajes mantienen ecosistemas altamente diversos. Una comprensión mejor de los procesos que mantienen esa diversidad podría resultar en una toma de decisiones y de manejo con mejores bases. Se formularon las siguientes preguntas para aumentar nuestro conocimiento sobre los procesos que controlan la diversidad de especies: 1) ¿Un aumento en la permanencia del flujo se correlaciona con aumento de la riqueza de especies de artrópodos terrestres y la comunidad vegetal ribereña? 2) ¿Es la ubicación en una red de corrientes un factor de control de la riqueza de especies? Los resultados preliminares de este estudio de varios años indican que la alta disponibilidad de agua en los cañones, presente en la superficie y las corrientes del subsuelo, mantiene una alta diversidad y abundancia de especies de plantas leñosas de dosel grande, lo que, a su vez, limita la cantidad de especies herbáceas, debido a la sombra y la hojarasca. Sin embargo, los artrópodos terrestres alcanzan su mayor diversidad en estos densos bosques ribereños. Los arroyos del piedemonte y las áreas más bajas de cañones con agua limitada tienen un dosel más abierto, pero mantienen un mayor número de especies herbáceas. Cada tipo de arroyo mantiene diferentes (pero superpuestas) comunidades de artrópodos y plantas, por lo tanto la combinación de diferentes tipos de corrientes mantiene colectivamente una gran diversidad.

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Riparian vegetation and disappearing groundwater. Over the past century in the southwestern United States, rapid economic growth, expanding urban centers and agriculture have driven steep increases in freshwater demands, which have been met through groundwater pumping, surface flow diversions, and dams - all of which alter water availability and flow patterns in rivers. These shifting baseline conditions, combined with episodic drought, have led both to the drying of river reaches that were once perennial as well as to the wetting of previously dry river segments. Drawing from case studies of rivers in southern Arizona including Cienega Creek, Garden Canyon, the San Pedro River, and the Santa Cruz River, we explore several scenarios: 1) the biological changes that occur in groundwater-dependent ecosystems as water tables deepen and no-flow periods increase, 2) the patterns and rates of vegetation change that occur when diversion and pumping pressures are reduced; and 3) the response of riparian vegetation to discharge of municipal effluent into stream channels.

Vegetación ribereña y desaparición de aguas subterráneas. Desde el siglo pasado en el suroeste de Estados Unidos, el rápido crecimiento económico, la expansión de los centros urbanos y la agricultura han aumentado la demanda de agua dulce, que se ha resuelto a través de bombeo del acuífero, desviaciones de corrientes en la superficie y presas, todo lo cual altera la disponibilidad de agua y los patrones de las corrientes de ríos. El cambio de estas condiciones básicas, combinado con la sequía, han llevado tanto al secado de tramos de ríos que antes eran perennes, y también ha causado que tramos anteriormente secos tengan agua. A partir de estudios de caso de ríos en el sur de Arizona, incluyendo los ríos Ciénega Creek, Garden Canyon, San Pedro, y Santa Cruz, exploramos varios escenarios: 1) los cambios biológicos que ocurren en los ecosistemas que dependen de aguas subterráneas, conforme baja el nivel freático y aumentan los períodos sin corriente, 2) los patrones e índices de cambio de vegetación que ocurren cuando se reduce el estrés por la desviación y el bombeo, y 3) la respuesta de la vegetación ribereña a la descarga de aguas residuales en los cauces de arroyos..

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Important bird areas of the Madrean Archipelago: A conservation strategy for avian communities. The Important Bird Areas (IBAs) Program is a worldwide program that identifies sites considered to provide important habitats for avian species. Criteria for designation are species abundance, diversity and range restriction. The Madrean Archipelago has a diverse range of identified IBAs that feature riparian, wetland, grassland and Madrean oak woodland habitats. Five of the 24 IBAs in the region are globally significant: the Chiricahua Mountains, San Pedro Riparian National Conservation Area, Lower San Pedro River, Whitewater Draw State Wildlife Area, and Willcox Playa. In Mexico, the network of IBAs continues in the Sierra Madrean Sky Islands. The purpose of designation as an IBA is highlighting the value of specific sites. The lower elevation riparian IBAs are vital for neotropical migrants in the spring as well as provide habitat for resident species. In these habitats, which are particularly productive in the spring, these species can refuel and rest before continuing on their journey north to breeding grounds. The high elevation "sky island" IBAs are very productive in the fall and serve as vital stop over points for migrants headed south and many complete their interrupted molt in these IBAs. This network serves to identify those habitats most important to conserve native birds.

Áreas importantes para las aves del Archipiélago Madreño: una estrategia de conservación para las comunidades de aves. El Programa de Áreas Importantes para la Conservación de las Aves (IBAs) es un programa mundial que identifica sitios que proporcionan hábitats importantes para especies de aves. Criterios para la designación son la abundancia de la especie, diversidad, y restricción de localización. El Archipiélago Madreño tiene una amplia gama de IBAs identificadas que cuentan con hábitats ribereños, humedales, pastizales y bosques de encino Madreño. Cinco de las 24 IBAs en la región son de importancia mundial: las montañas Chiricahua, el Área Nacional de Conservación Ribereña de San Pedro, el Área Estatal de Vida Silvestre Whitewater Draw, y Playa Willcox. En México, la red de IBAs continúa en las Islas Serranas Madreñas. El propósito de la designación como IBA es resaltar el valor de sitios específicos. Las IBAs ribereñas de menor elevación

son vitales para aves migratorias neo-tropicales en la primavera, y también son el hábitat de especies residentes. En estos hábitats, que son especialmente productivos en la primavera, estas especies pueden repostar y descansar antes de continuar su viaje hacia el norte a las zonas de cría. Las IBAs de alta elevación en las “Islas Serranas” son muy productivas en el otoño y sirven como parada vital para aves migratorias hacia el sur y muchos completan su muda de plumaje en estas IBAs. Esta red sirve para identificar los hábitats más importantes para la conservación de las aves nativas.

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Estimating species richness and occupancy of mammals in Saguaro National Park using remote camera traps. Saguaro National Park has numerous species of mammals, though most are hard to document and monitor due to their elusive nature. From May 2010 to April 2011 we used remote cameras to monitor mammal activity equally across stratified 1km plots based on elevation in an attempt to estimate species richness (number of species present) and occupancy of common species. We used 48 cameras placed in 60 randomly selected plots (4 cameras per plot) in 6-week intervals at random locations in both districts of the park (totaling 240 camera locations). We present findings from this study, including the feasibility of using remote camera traps to estimate species richness and occupancy; other additional valuable information that can be gained from using remote cameras; and how this information can be used to interpret mammals to public and contribute to better resource management.

Estimación de la riqueza de especies y ocupación de mamíferos en el área protegida Saguaro National Park usando cámaras trampa remotas. El Parque Nacional del Saguaro tiene numerosas especies de mamíferos, aunque la mayoría son difíciles de documentar y monitorear debido a su naturaleza elusiva. Desde mayo de 2010 hasta abril de 2011 utilizamos cámaras remotas para monitorear la actividad de mamíferos equitativamente en parcelas de 1 km, estratificadas por elevación, con el fin de estimar la riqueza de especies (número de especies presentes) y la ocupación de las especies más comunes. Utilizamos 48 cámaras colocadas en 60 parcelas seleccionadas al azar (4 cámaras por parcela) en intervalos de 6 semanas en lugares al azar en ambos distritos del parque (un total de 240 localidades de cámaras). Se presentan los resultados de este estudio, incluyendo la posibilidad de utilizar cámaras trampa remotas para estimar la riqueza de especies y la ocupación; otra información valiosa que puede obtenerse con el uso de cámaras remotas, y como se puede usar estos registros para informar al público sobre mamíferos y contribuir a un mejor manejo de los recursos.

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Long-term dynamics of Lowland Leopard Frogs (*Rana yavapaiensis*). Amphibians appear to be declining throughout the globe. In the Desert Southwest, a number of amphibian species, particularly ranid frogs, have experienced dramatic decreases in population, local extinctions, and regional extinctions. Although these declines are well documented, surprisingly little is known about the natural long-term dynamics of amphibian populations. Lowland leopard frogs (*Rana yavapaiensis*) in the Rincon Mountains of Saguaro National Park are faced with challenges of drought, sedimentation of pools, potential invasion of American bullfrogs, and disease. We present findings from a 15 year monitoring program of lowland leopard frogs in the park which provides evidence on which of these challenges pose the greatest threat to occupancy and abundance of lowland leopard frogs.

Dinámicas a largo plazo de las ranas yavapai (*Rana yavapaiensis*). Los anfibios parecen estar disminuyendo alrededor el mundo. En el desierto del suroeste norteamericano, un número de especies de anfibios, en particular ranas verdaderas, han experimentado una disminución drástica en la población, extinciones locales y regionales. A pesar de que estas disminuciones están bien documentadas, sorprendentemente se sabe poco acerca de las dinámicas naturales de las poblaciones de anfibios a largo plazo. Las ranas yavapai (*Rana yavapaiensis*) de las montañas Rincón del Parque Nacional Saguaro se enfrentan a retos de sequía, sedimentación de las tinajas, invasión potencial de la rana toro americana, y enfermedades. Presentamos los resultados de un programa de seguimiento de 15 años de las ranas yavapai de esta área, que ofrece datos sobre cuál de estos desafíos plantea la mayor amenaza para la ocupación y la abundancia de ranas yavapai.

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Clonal growth and genetic diversity in the endangered Huachuca Water Umbel from Southwestern Cienegas. The Huachuca Water Umbel, *Lilaeopsis schaffneriana* subsp. *recurva* (Apiaceae) is an endangered plant found in cienega wetlands dispersed throughout southeastern Arizona and northern Sonora, Mexico. Very little is known about how much genetic variation is found within populations of this herbaceous perennial, how different populations and watersheds are from one another, how much genetic exchange takes place among populations, and how prevalent vegetative (rhizomes) and sexual (flowers and fruits) reproduction are within populations. We examined genetic diversity within and among ten populations of the Huachuca Water Umbel sampled from across its range using DNA microsatellite markers. We found that patterns of genetic diversity within populations were indicative of extensive vegetative reproduction. In general, most of the genetic diversity found in the species was evenly distributed across populations. Genetic structure when found appeared to be influenced by geography, with populations becoming

more differentiated as proximity of watersheds increased. These results provide important information for improving ongoing conservation efforts including ex-situ collections and reintroductions and shed light on the biology and connectivity of plant populations in southwestern cienegas.

Propagación clonal y diversidad genética de la planta en peligro de extinción umbela de agua de las Huachucas, en las ciénegas del Suroeste Norteamericano. La umbela de agua de las Huachucas, *Lilaeopsis schaffneriana* subsp. *recurva* (Apiaceae) es una planta en peligro de extinción que se encuentran en las ciénegas dispersas en el sureste de Arizona y el norte de Sonora, México. Se sabe muy poco sobre qué tanta variación genética se encuentra dentro de las poblaciones de esta planta herbácea perenne, qué tan diferentes son las poblaciones y las subcuencas hidrográficas, qué tanto intercambio genético existe entre las poblaciones, y qué tan común es la reproducción vegetativa (rizomas) y sexual (flores y frutos). Analizamos la diversidad genética dentro y entre diez poblaciones de la umbela de agua de las Huachucas, con muestras tomadas de toda el área de distribución utilizando marcadores microsatélites de ADN. Encontramos que los patrones de diversidad genética dentro de las poblaciones son indicadores de extensa reproducción vegetativa. En general, la mayoría de la diversidad genética encontrada en la especie se distribuye uniformemente a través de las poblaciones. La estructura genética, cuando se encontró, parece estar influenciada por la geografía, con poblaciones cada vez más diferenciadas cuanto más cerca de las cuencas hidrográficas. Estos resultados aportan información importante para mejorar los trabajos de conservación, incluyendo recolecciones y reintroducciones in situ y esclarecen la biología y la conectividad de las poblaciones de plantas en las ciénegas del Suroeste.

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Sacaton riparian grasslands of upper Ciénega Creek watershed, SE Arizona: Distribution and condition classification using state-and-transition models. Riparian grasslands dominated by *Sporobolus wrightii* (big sacaton) were once widely distributed in the intermountain basins of the Madrean Archipelago. The upper Cienega Creek watershed in SE Arizona still harbors extensive sacaton stands. These alluvial grasslands are recognized as key resources for watershed function, livestock, and wildlife. Documenting their extent and ecological state is important for informing management in this valley and for contributing to a clearer picture of this communities' status across the region. Our objectives were to map the distribution of sacaton; qualitatively assess stands of sacaton into condition classes; and test mapping and assessment methods for use in other valley bottoms in the region. We used a two-step approach: interpretation of aerial photography followed by field reconnaissance. Field work consisted of qualitative, rapid assessments of ecological state using the NRCS State-and-Transition model for the Loamy Bottom Ecological Site. The best condition "Sacaton Grassland" class occupies nearly half of alluvial habitats evaluated, with the remainder in various states of degradation, recovery, or succession to mesquite woodland. Our observations suggest potential modifications to the State-and-Transition model that might more accurately reflect site potential, likelihood of transitioning to other states, and management strategies tailored to maintaining or improving condition.

Pastizales ribereños de zacatón de la cuenca alta de Ciénega Creek en el sureste de Arizona: Clasificación de la distribución y la condición usando modelos de estado y transición. Los pastizales ribereños dominadas por zacatón (*Sporobolus wrightii*) tenían una distribución amplia en las cuencas entre montañas del Archipiélago Madrense. En la parte alta de la cuenca Ciénega Creek en el sureste de Arizona todavía existen áreas extensas de zacatón. Se reconocen estos pastizales aluviales como un recurso vital para la función de la cuenca, el ganado y la fauna. Es importante documentar el estado ecológico y su extensión para las actividades de manejo en este valle y tener una imagen más clara del estado de esta comunidad en la región. Nuestro objetivo fue generar un mapa de distribución del zacatón; evaluar cualitativamente las áreas de zacatón según su condición y probar métodos de elaboración de mapas y evaluación para su uso en otros valles ribereños de la región. Usamos un método con dos partes: interpretación de fotografía aérea seguido por un reconocimiento de campo. El trabajo de campo consistió de una evaluación cualitativa rápida del estado ecológico usando el modelo de estado y transición del NRCS para el sitio ecológico de Loamy Bottom. La clase con la condición mejor de "Pastizal de zacatón" ocupa casi la mitad de los hábitats de la zona aluvial evaluados, con el resto en varios estados de degradación, recuperación o sucesión a mezquital. Nuestras observaciones sugieren una modificación al modelo de estado y transición que podría reflejar de una manera más exacta el potencial del sitio, probabilidad de transición y estrategias de manejo adaptadas para mantener o mejorar las condiciones.

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Monitoring restoration progress on Cuenca Los Ojos properties, Sonora Mexico. Watershed and grassland restoration began on Rancho San Bernardino (San Bernardino Cienega) in 1999. Since this time gabions, trincheras and berms for water retention have been constructed, and shrubs have been removed and re-seeded to native grass. In 2010, Cuenca Los Ojos initiated a restoration monitoring program. Landsat imagery was analyzed annually in June from 1984 through 2011 using ENVI Remote Sensing software to quantify land cover changes on all Cuenca Los Ojos properties in Sonora Mexico. Pre-restoration imagery was analyzed against post-restoration imagery to detect changes in the San Bernardino Cienega, grasslands, shrub lands, and riparian areas. Initial results suggest an increase of 1920 acres of riparian area on Rancho San Bernardino. Additionally, the Cienega has increased in size from 52 acres (pre-restoration) to 88 acres today. Landsat and SPOT Imagery from 2011 was ground-truthed using resource grade GPS and permanent transects were established in several locations. Wet-dry monitoring during the pre-monsoon month of June 2011 was done to determine perennial water at Rancho San Bernardino. Permanent Gully profile tran-

sects were re-measured in 2011 to determine how much sediment has been captured due to watershed restoration efforts (repeating a study done in 2000 by Noelia de la Torre-Univ. of Sonora). Vegetation was analyzed along the gully profiles to determine changes due to restoration.

Seguimiento del progreso de restauración en las propiedades de Cuenca Los Ojos, Sonora, México. La restauración de la cuenca y el pastizal empezaron en el rancho San Bernardino (Ciénega de San Bernardino) en 1999. Desde entonces se han construido gaviones, trincheras y bordos para retener el agua; se removieron los arbustos y se sembraron zacates nativos. En 2010, Cuenca Los Ojos inició un programa para darle seguimiento al progreso de restauración. Se analizaron imágenes Landsat anualmente, cada junio, desde 1984 hasta 2011 usando el software de teledetección ENVI para cuantificar los cambios de cobertura vegetal en todas las propiedades de Cuenca Los Ojos, Sonora, México. Las imágenes tomadas antes de la restauración se compararon con imágenes tomadas después para detectar cambios en la Ciénega de San Bernardino, pastizales, matorrales y áreas ribereñas. Los resultados iniciales muestran un aumento de 780 hectáreas de áreas ribereñas en el rancho San Bernardino. Adicionalmente, la ciénega ha aumentado en tamaño, desde 21 hectáreas (antes de la restauración) a 35 hectáreas actualmente. Imágenes SPOT y Landsat del año 2011 fueron verificadas en tierra usando un sistema de GPS y se establecieron transectos permanentes en varios lugares. Se hizo el seguimiento húmedo-seco durante el mes de junio de 2011, antes del monzón, para determinar las aguas perennes del rancho San Bernardino. Se midieron de nuevo los transectos permanentes del perfil de barrancos, en 2011, para determinar cuanto sedimento se había capturado con el trabajo de restauración (repitiendo una investigación hecha en 2000 por Noelia de la Torre- Univ. de Sonora). Se analizó la vegetación a lo largo del perfil del barranco para determinar los cambios por la restauración.

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Using remote sensing to model fuel moisture stress for Sky Islands forests. Wildland fires have become increasingly devastating in the Southwestern United States in the past decade, including the biodiversity rich Sky Islands of southeastern Arizona. Fire risk in this region is increased during drought periods that lead to low fuel moisture conditions. Statistical transformations of spectral indices derived from remote sensing provide a way to identify areas of high fuel moisture stress in vegetation. The Moderate Resolution Imaging Spectroradiometer (MODIS) provides near infrared and visible land cover data of the Sky Islands from 2000 until now. The inverse z scores of the Normalized Difference Vegetation Index (NDVI) produce a Fuel Moisture Stress Index (FMSI) that can be used to identify when and where vegetation is under moisture stress. The inverse z scores of these indices standardize the pixel values that may be confounded by pixels that may have the same values, but completely different land cover types and topographies. By superimposing FMSI data from regions in years of known high fuel moisture stress, we can establish a procedure to identify areas of high moisture stress to predict years of widespread fire occurrence. FMSI is a spatially-explicit approach to modeling the role of interannual climate variability in modulating time-varying fire risk.

Uso de sensores remotos para el modelado de vegetación combustible en los bosques de las Islas Serranas. Desde la década pasada los incendios forestales se han vuelto cada vez más devastadores en el Suroeste de Estados Unidos, incluyendo las Islas Serranas del sureste de Arizona, una región de gran biodiversidad. El riesgo de incendios en esta zona aumenta durante los periodos de sequía que causa condiciones de humedad baja en la vegetación combustible. Las transformaciones estadísticas de índices espectrales derivadas de los datos obtenidos por sensores remotos es una manera de identificar áreas de alto riesgo de vegetación combustible por estrés de humedad. El espectroradiómetro de imágenes de media resolución (MODIS) proporciona infrarrojo cercano y datos visibles de la cobertura del suelo de las Islas Serranas desde el año 2000 hasta hoy. Las puntuaciones z inversas del índice de vegetación de diferencia normalizada (NDVI por sus siglas en inglés) produce un índice de la falta de humedad del combustible (FMSI) que se puede usar para identificar el tiempo y lugar donde la vegetación está muy seca. Las puntuaciones z inversas de estos índices estandarizan los valores de los píxeles que se pueden confundir con píxeles que tienen el mismo valor pero que tienen tipos de cobertura de la tierra y topografías muy diferentes. Mediante la superposición de los datos acumulados por el FMSI de las regiones en los años conocidos de alto riesgo de vegetación combustible por estrés de humedad, podemos establecer un proceso para identificar áreas de alto riesgo por estrés de humedad para predecir años cuando ocurrirán incendios grandes. EL FMSI es un enfoque espacialmente explícito para modelar la influencia de la variabilidad del clima interanual en la modulación del riesgo de incendios en tiempo variable.

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Mapping perennial flow in the San Pedro River: A binational monitoring project. The San Pedro River flows 279 km (173 mi) north from its headwaters in Sonora, Mexico, to its confluence with the Gila River in Arizona, USA. It is one of the few remaining free-flowing perennial streams in this semi-arid region, but has lost more than 50% of its perennial length. To monitor the river's status, an annual monitoring program was initiated in 1999 to map surface water during the driest part of the year. The length of surveyed reaches has been gradually increasing, and in 2011 included 222 km (138 mi) of mainstem, along with 154 km (96 mi) of tributaries, in both the U.S. and Mexico. Results show a decreasing trend in some areas and increases in others, likely due to localized effects of groundwater pumping or recovery from pumping which has recently been stopped. While some reaches were consistently wet and thus perennial, total wetted length varied widely from year to year within most analysis segments. The results have been used for a variety of management and scientific purposes. This project also demonstrates the power of long-term collaborative efforts across the international border, and between government agencies, non-governmental organizations, and citizen-science volunteers.

Cartografía de corrientes perennes del río San Pedro, un proyecto de monitoreo binacional. El río San Pedro recorre 279 km (173mi) hacia el norte de su nacimiento en Sonora, México hasta que se junta con el río Gila en Arizona, E.U. Es uno de los pocos ríos de corriente libre perenne que quedan en esta región semiárida, pero ha perdido más del 50% de su longitud perenne. Para monitorear el río, se inició un programa de monitoreo anual en 1999 para hacer mapas de las aguas superficiales durante el periodo más seco del año. La longitud de los tramos estudiados ha aumentado gradualmente y en 2011 fueron 222 km (138 mi) en el cauce principal y 154 km (96 mi) de corrientes tributarias tanto en E.U. y México. Los resultados muestran una tendencia a disminuir en unas áreas y aumentar en otras, probablemente se debe a los efectos localizados del bombeo de agua subterránea o la recuperación del bombeo que recientemente ha parado. Mientras unos tramos tienen agua constante y por lo tanto son perennes, la longitud con agua varió ampliamente año con año en la mayoría de los segmentos analizados. Estos resultados se han usado para diversos fines científicos y de manejo. Este proyecto también muestra el poder de los trabajos de colaboración a largo plazo a través de la frontera internacional y entre las agencias de gobierno, organizaciones no gubernamentales y voluntarios de la ciencia ciudadana.

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Squirrels of Sonora. Squirrels (Rodentia: Sciuridae) are usually good indicators of the conservation status of ecosystems, as they have strong relationships with particular plant associations, plus they have a great importance in the food chain for being consumers of large amounts of seeds and insects. Sonora is one of the states that has the biggest diversity of species of squirrels in Mexico, with 10 species in five genera, representing 29% and 71% of the total for Mexico, respectively. These species represent three faunal influences: species of temperate forests of the Sierra Madre Occidental, desert species with a range that extends into Arizona and grassland species that extend into New Mexico and Chihuahua. Besides their representation in the state and its ecological and biogeographical importance, actual knowledge is currently unknown in the state. This paper presents more information about squirrels of Sonora.

Ardillas del Estado de Sonora. Las ardillas (Rodentia: Sciuridae) suelen ser buenos indicadores del estado de conservación de los ecosistemas, ya que presentan una fuerte relación con asociaciones vegetales particulares, además de que son de gran relevancia en las cadenas tróficas al ser consumidores de grandes cantidades de semillas y de insectos. Sonora es uno de los estados que presenta una mayor diversidad de especies de ardillas en México, con 10 especies en cinco géneros, que representan el 29% y 71% del total para México, respectivamente. Estas especies representan tres influencias faunísticas: especies de bosques templados de la Sierra Madre Occidental, especies desérticas con un amplio rango que se extiende hasta Arizona y especies de pastizales que se extienden hasta Nuevo México y Chihuahua. No obstante su representatividad en el estado y su importancia ecológica y biogeográfica, se desconoce el estado actual de su conocimiento en el estado. Este trabajo pretende dar a conocer más información acerca de las ardillas del estado de Sonora.

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Floristic analysis of Ojo de Agua Tonibabi, Sierra La Madera, Sonora, Mexico. Ojo de Agua Tonibabi is an area of great historical and biological interest located 16 km northeast of Moctezuma, Sonora, Mexico at the base of the Sierra La Madera (29°48'10"N 109°40'49"W, 624 m elevation). Plants were collected, observed, and photographed to document floristic diversity in the area on six outings between April and November 2011. The vegetation is tropical foothills thornscrub. In the areas surrounding the spring and permanent streams, there is riparian vegetation with Goodding willow (*Salix gooddingii*). Collections were identified through comparisons with specimens in University of Arizona and the Universidad de Sonora Herbaria. A total of 143 species in 114 genus and 42 families were identified. The families with the greatest number of species are Fabaceae (26), Asteraceae (15), Euphorbiaceae (11), Convolvulaceae (8), Poaceae (8), and Cactaceae (9). Annual plants are the most abundant life form (41 taxa), followed by perennial herbs (32), trees (22), shrubs (11), vines (9), succulents (9), grasses (8), subshrubs (7), and aquatic herbs (1).

Análisis florístico del Ojo de Agua Tonibabi, Sierra La Madera, Sonora, México. El Ojo de Agua Tonibabi es un área de gran interés biológico e histórico localizado a 16 km al noreste de Moctezuma, Sonora, México. Esta ubicado al pie de la Sierra La Madera a los 29°48'10" N y 109°40'49" O y una altitud de 624 msnm. Empezamos un inventario de la diversidad florística en esta área con seis salidas entre abril y noviembre del 2011, para hacer observaciones y coleccionar ejemplares. La vegetación es de origen tropical, principalmente matorral espinoso. En los alrededores del ojo y arroyos húmedos hay vegetación riparia con presencia de sauz (*Salix gooddingii*). Se identificaron ejemplares mediante visitas a los herbarios de la University of Arizona y Universidad de Sonora. Como resultado se tiene 143 especies en 114 géneros y 42 familias. Las familias con mayor riqueza florística son Fabaceae (26), Asteraceae (15), Euphorbiaceae (11), Convolvulaceae (8), Poaceae (8) y Cactaceae (9). Las herbáceas anuales representan la forma biológica más abundante (41 taxa), seguida por las hierbas perennes (32), árboles (22), arbustos (11), enredaderas (9), suculentas (9), zacates (8), subarbustos (7) y hierbas acuáticas (1).

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Identifying linkages for jaguar population connectivity in northwest Mexico. The establishment of biological corridors and linkages has been proposed as a conservation strategy to maintain connectivity in large carnivore populations that live in highly fragmented landscapes and require extensive home ranges. Because jaguar population connectivity in their most northern distributional limit is unknown and linkages among populations have not been detected, we proposed to evaluate connectivity of jaguar populations and to identify potential linkages that promote jaguar movements between populations. A virtual landscape where individuals moved was developed by SAMT software applying an Individual Based Movement Model. The virtual landscape was developed including variables of elevation, land use types, cattle density and human impact. Population parameters include mortality, displacement ability, and movement direction. The linkages were identified using GIS tools. Our results suggest that most of the dispersal jaguar events are located through the Sierra Madre Occidental, showing differences between sex and populations. Because most of the linkages important for jaguar populations are in private lands with livestock management, we propose legal protection of them by state authorities following an archipelago reserves approach.

Identificando eslabones para la conectividad de las poblaciones de jaguar en el noroeste de México. El establecimiento de corredores biológicos y eslabones han sido propuestos como una estrategia de conservación para mantener la conectividad en poblaciones de grandes carnívoros que viven en paisajes altamente fragmentados. Debido a que se desconoce la conectividad de las poblaciones de jaguar en su límite más norteño de distribución y que los eslabones entre las poblaciones no han sido identificados, nos propusimos evaluar la conectividad de las poblaciones e identificar los eslabones potenciales que promueven los movimientos de jaguares entre las poblaciones. Se desarrolló un paisaje virtual donde los individuos se movieron aplicando un Modelo de Movimiento Basado en Individuos en el programa SAMT. El paisaje virtual incluye variables de altitud, tipos de uso de suelo, densidad de ganado e impacto humano. Los parámetros de poblaciones fueron mortalidad, habilidad para desplazarse y dirección de movimientos. Los eslabones se identificaron con herramientas de SIG. Nuestros resultados sugieren que la mayoría de los eventos de dispersión se localizan a lo largo de la Sierra Madre Occidental, mostrando diferencias entre sexos y poblaciones. Debido a que los eslabones más importantes se localizan en tierras privadas ganaderas, se propone su protección legal con autoridades estatales, siguiendo el enfoque de las reservas archipiélagos.

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Comparison of the tropical floras of Sierra la Madera and the Sierra Madre Occidental, Sonora, Mexico. The floras of the tropical vegetation in the Sky Island Sierra la Madera (SMA) near Moctezuma in central Sonora (30°00'N 109°18'W) and the Yécora (YEC) area in the Sierra Madre Occidental (SMO) in eastern Sonora (28°25'N 109°15'W) were compared. The areas are 175 km apart. Tropical vegetation includes foothills thornscrub (FTS) in both areas and tropical deciduous forest (TDF) in the Yécora area. A total of 893 vascular plant taxa are known from these areas with 433 taxa in FTS and 793 in TDF. FTS in SMA and YEC (near Cúrea) had 220 and 298 taxa, with most of them also in TDF (69.5% and 82.9%). Only 83 taxa in TDF were shared between SMA and YEC (37.7% and 27.9% of the floras). The 49 FTS species in SMA but not YEC were not in TDF either, reflecting biotic influences from the Sonoran Desert (10), southwestern United States (8), Madrean Archipelago (6), and a few from oak woodland and tropical western Mexico. One species (*Pseudabutilon thurberi*) is endemic to central Sonora and adjacent Arizona. Affinities to the New World tropics are very strong in both areas. The structural dominants that define FTS are widespread, but composition varies greatly locally.

Comparación de la flora tropical de la Sierra la Madera con la Sierra Madre Occidental de Sonora, México. Se comparó la flora de la vegetación tropical de la Sierra la Madera (SMA) una Isla Serrana cerca de Moctezuma en el centro de Sonora (30°00'N 109°18'W) y el área de Yécora (YEC) en la Sierra Madre Occidental (SMO) del este de Sonora (28°25'N 109°15'W). Donde una distancia de 175 km separa las dos regiones. La vegetación tropical incluye matorral espinoso de piedemonte (MEP) en las dos áreas y selva baja caducifolia (SBC) en el área de Yécora. Se tienen reportados 893 taxones de plantas vasculares de estas áreas con 433 taxones en MEP y 793 en SBC. El MEP en la SMA y YEC (cerca de Cúrea) tiene 220 y 298 taxones respectivamente, muchos de ellos también se encuentran en la SBC (69.5% y 82.9%). Sólo 83 taxones de la SBC se comparten entre la SMA y YEC (37.7% y 27.9% de las floras). Las 49 especies de MEP en la SMA pero no en YEC tampoco están presentes en la SBC, lo que refleja las influencias bióticas del Desierto Sonorense (10), suroeste de Estados Unidos (8), Archipiélago Madreño (6) y unas cuantas del encinal y la región tropical del occidente de México. Una de las especies (*Pseudabutilon thurberi*) es endémica del centro de Sonora y la parte adyacente de Arizona. Las afinidades con las zonas tropicales de América son muy fuertes en las dos áreas. Las especies dominantes que determinan la estructura del MEP tienen una distribución amplia, pero la composición varía bastante localmente.

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Preliminary flora of the Sierra Bacadéhuachi, Sonora, Mexico. The Sierra de Bacadéhuachi in east-central Sonora is the westernmost mountain range in the Sierra Madre Occidental (SMO), located east of Bacadéhuachi, Municipio de Bacadéhuachi, 34 kilometers east of the Chihuahua border, and 165 km south of the Arizona border. The southern portion of the range is in the Ríos Nácori Chico and Riíto drainages, both part of the greater Río Yaqui system. The vegetation ranges from lowland foothills thornscrub (FTS) up through desert grassland to oak woodland and pine-oak forest. The flora was sampled in December 1995 (montane forests), July 2008 (FTS), June, August, and September 2011, and March 2012 (Madrean Archipelago Biodiversity Assessment [MABA] Expeditions). The flora totals 442 taxa in 297 genera and 96 families. The most species-rich families and genera are Asteraceae (53 taxa), Fabaceae (48 taxa each), Poaceae (46 taxa), *Quercus* (11 species), *Cheilanthes* (8 species), *Muhlenbergia* (7 species), and *Bouteloua* (6 species) Twenty-two species are non-native (5.0%), 10 of them grasses. All observations and collections are in the MABA database (www.madreal.org). Although tree composition and structure of the upland woodlands and forests are similar to the Yécora area to the southeast, the preliminary Bacadéhuachi flora appears to be much less diverse.

Flora preliminar de la Sierra de Bacadéhuachi, Sonora, México. La Sierra de Bacadéhuachi en el este centro de Sonora es la región montañosa más al oeste en la Sierra Madre Occidental (SMO), ubicada al este de Bacadéhuachi, municipio del mismo nombre, 34 km al este de la frontera con Chihuahua y 165 km al sur de la frontera con Arizona. El sur de esta sierra se localiza en la cuenca de los ríos Nácori Chico y Riíto, afluentes de la gran cuenca del río Yaqui. La vegetación varía desde matorral espinoso de piedemonte (MEP) en la parte baja, a pastizal del desierto y bosques de encino y de pino encino en la parte alta. La flora se colectó en diciembre de 1995 (bosques de montaña), julio de 2008 (MEP), junio, agosto y septiembre de 2011 y marzo de 2012 (expediciones del proyecto Evaluación de la Biodiversidad del Archipiélago Madreño [MABA]). La flora actual contiene 442 taxones en 297 géneros y 96 familias. Las familias y géneros más numerosos son: Asteraceae (53 taxones), Fabaceae (48), Poaceae (43), *Quercus* (11 especies), *Cheilanthes* (8), *Muhlenbergia* (7 y *Bouteloua* (6). Veinti-dós especies son introducidas (5.0%), 10 de ellas zacates. Todos los registros de observaciones y colectas se pueden consultar en la base de datos MABA (www.madreal.org). Aunque la estructura y la composición de los bosques altos es similar al área de Yécora en el sureste, la flora preliminar de Bacadéhuachi parece ser menos diversa.

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Comparison of preliminary herpetofaunas of the Sierras la Madera (Oposura) and Bacadéhuachi with the mainland Sierra Madre Occidental in Sonora, Mexico. Amphibians and reptiles observed in the Sierra la Madera, an isolated Sky Island mountain range in east-central Sonora, and the Sierra de Bacadéhuachi, the westernmost Sierra Madre Occidental (SMO) range, were compared with the herpetofauna of the Yécora area in eastern Sonora in the main Sierra Madre Occidental. Four areas in the Sierra la Madera near Moctezuma were visited in November 1981, September 2003, July 2009, and on a Madrean Archipelago Biodiversity Assessment (MABA) Expedition in August 2010. MABA Expeditions went to the Sierra de Bacadéhuachi in August and September 2011, and March 2012. Observations and photos in the Sierra la Madera (59 species) and the Sierra de Bacadéhuachi (30 species) are in the online MABA database (madreal.org). About 92 species are known from along MEX 16 in the Municipio de Yécora. Seven species in the Sky Island ranges were not in the SMO fauna. Although the Sky Island inventories are incomplete, it is clear that the herpetofauna of the SMO is much more diverse than any Sky Island fauna. Madrean species dominate the Sky Island faunas, which are mixtures of species with tropical, desert and northern temperate biotic affinities.

Comparación de las herpetofaunas preliminares de la Sierra la Madera (Oposura) y Sierra de Bacadéhuachi, Sonora, México con la Sierra Madre Occidental. Los anfibios y reptiles observados en la Sierra la Madera, una Isla Serrana aislada en el este-centro de Sonora y la Sierra de Bacadéhuachi, la cordillera más al oeste de la Sierra Madre Occidental (SMO) se compararon con la herpetofauna del área de Yécora en el este de Sonora en la Sierra Madre Occidental. Cuatro áreas en la Sierra la Madera cerca de Moctezuma se visitaron en noviembre de 1981, septiembre de 2003, julio de 2009 y en una expedición del proyecto de Evaluación de la Biodiversidad del Archipiélago Madreño (MABA) en agosto de 2010. Las expediciones a la Sierra de Bacadéhuachi se realizaron en agosto y septiembre de 2011 y marzo de 2012. Las observaciones e imágenes de la Sierra la Madera (59 especies) y de la Sierra de Bacadéhuachi (30 especies) se pueden consultar en la base de datos en línea MABA (madreal.org). Cerca de 92 especies son reportadas de la carretera federal MEX 16 en el municipio de Yécora. Siete especies de estas Islas Serranas no están en la fauna de la SMO. Aunque los inventarios de Islas Serranas son incompletos, es evidente que la herpetofauna de la SMO es mucho más diversa que cualquier fauna de Isla Serrana. Las especies madreñas dominan las faunas de las Islas Serranas, las que se componen de especies con afinidades bióticas tropicales, desérticas y templadas del norte.

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Flora of Chihuahuan Desertscrub on Limestone in northeastern Sonora, Mexico. Transects were done in desertscrub on limestone to characterize the flora of the westernmost Chihuahuan Desert. Most of the sites (15) were in the Municipios of Agua Prieta and Naco in northeastern Sonora. Single sites were near Ascensión in northwestern Chihuahua and east of Douglas in southeastern Arizona. A total of 250 species were recorded on the transects. When analyzed by life form, perennial herbs (60 species) were the most numerous, followed by annual herbs (45 species), subshrubs (37 species), and woody shrubs (34 species). The most diverse limestone floras were on Rancho La Morita in the Municipio of Naco. Two transects on a hill west of Arroyo La Bellota had 90 and 121 taxa. Ocotillo (*Fouquieria splendens*), sotol (*Dasyllirion wheeleri*), beargrass (*Nolina microcarpa*), and littleleaf sumac (*Rhus microphylla*) were dominants. On the nearby Cerro La Bruja transect (96 taxa), Chihuahuan whitethorn acacia (*Acacia neovernicosa*), ocotillo, and shrubby senna (*Senna wislizenii*) were common on a grassy, limestone slope. The flora was also diverse in the La Calera area on the Sierra Anibácachi in the Municipio of Agua Prieta with 93 taxa on a transect dominated by Sonoran rosewood (*Vauquelinia californica* var. *pauciflora*), a rare Sonoran shrub.

Flora del matorral del Desierto Chihuahuense en las calizas del noreste de Sonora, México. Se utilizó el método de transectos en matorral desértico de caliza para evaluar la flora de la región más occidental del Desierto Chihuahuense. La mayoría de los sitios de estudio (15) se ubicaron en los municipios de Agua Prieta y Naco en el noreste de Sonora. También se evaluaron sitios únicos cerca de Ascensión en el noroeste de Chihuahua y al este de Douglas al sureste de Arizona. Se registraron un total de 250 especies en los transectos. Al hacer el análisis por forma de vida se encontró que las hierbas perennes (60 especies) fueron las más numerosas, seguidas por las hierbas anuales (45 especies), subarbustos (37 especies) y arbustos leñosos (34 especies). Las floras de caliza más diversas se encontraron en rancho La Morita en el municipio de Naco. Dos transectos en este sitio, en un cerro al oeste del arroyo La Bellota registraron 90 y 121 taxones. . Ocotillo (*Fouquieria splendens*), sotol (*Dasyllirion wheeleri*), palmilla (*Nolina microcarpa*) y limita (*Rhus microphylla*) fueron las especies dominantes. En el transecto del cerro la Bruja (96 taxones), cerca del arroyo La Bellota, vinorama (*Acacia neovernicosa*), ocotillo y *Senna wislizenii* fueron comunes en una ladera con suelos de caliza y zacates abundantes. La flora también se encontró diversa en el área de La Calera, en la Sierra Anibácachi del municipio de Agua Prieta con 93 taxones en un transecto dominado por *Vauquelinia californica* var. *Pauciflora*, un arbusto raro en Sonora.

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Biodiversity in the Madrean Archipelago of Sonora, México. The Madrean Archipelago is the area of isolated Sky Island mountain ranges between the Sierra Madre Occidental (SMO) in Sonora and Chihuahua and the Mogollon Rim in New Mexico and Arizona. Five biotic provinces converge in the area: tropical temperate SMO, temperate Rocky Mountains, Great Plains-Chihuahuan Desert, Sonoran Desert, and western Mexico lowlands tropics. The transition between the New World tropics and the northern temperate zone is 28-29°N in east-central Sonora. In 2009 Sky Island Alliance initiated the Madrean Archipelago Biodiversity Assessment (MABA) program to document distributions of all plants and animals in the Madrean Archipelago from historical (museum collections, literature, etc.) sources, and observations on expeditions to high diversity mountain ranges of conservation interest. Species numbers in the MABA database provide preliminary diversity estimates for the Madrean Archipelago in Sonora. There are ca. 2880 plant taxa in northeastern Sonora. Insects are very diverse, but only 1380 taxa are documented in the Sky Islands Region. Vertebrates are better represented: fish (39 species), amphibians and reptiles (104 species), birds (358 species), and mammals (76 species). Surprising, diversity appears to decrease southward, but probably reflects the NNW-SSE orientation of the ranges, and decreasing area and fewer biological inventories to the south.

Biodiversidad del Archipiélago Madreño de Sonora, México. El área del Archipiélago Madreño lo forman las cadenas montañosas Islas Serranas aisladas entre la Sierra Madre Occidental (SMO) en Sonora y Chihuahua y la región del Mogollón Rim en Nuevo México y Arizona. Cinco provincias bióticas convergen en el área: SMO tropical templada, Montañas Rocallosas templadas, Desierto Chihuahuense – Grandes Llanuras, Desierto Sonorense y la región tropical del occidente de México. La transición entre los trópicos de América y la zona templada del norte se localiza en 28-29°N en la parte este centro de Sonora. Sky Island Alliance empezó el programa Evaluación de la Biodiversidad del Archipiélago Madreño (MABA) en 2009 para documentar la distribución de las especies de plantas y animales en el Archipiélago Madreño con registros históricos (colecciones de museos, literatura, etc.) y observaciones hechas en expediciones a sierras con alta diversidad y de interés para su conservación. Estimaciones preliminares de la diversidad del Archipiélago Madreño en Sonora se obtienen a través de las especies en la base de datos MABA. Se cuenta con cerca de 2880 taxones de plantas en el noreste de Sonora. Los insectos tienen una diversidad alta, pero sólo 1380 taxones están documentados en la Región de las Islas Serranas. Los vertebrados están mejor representados: peces (39 especies), anfibios y reptiles (104 especies), aves (358 especies) y mamíferos (76 especies). Es sorprendente que la diversidad parece ser que disminuye hacia el sur, pero probablemente refleja la orientación NNO-SSE de las cordilleras, reducción del área y muy pocos inventarios biológicos en el sur.

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The influence of plant phenological patterns on migrating neotropical migrant birds in western North America. In western North America, migration patterns of neotropical land birds evolved along landscapes at different elevations and within heterogeneous and patchy environments. Western migrant land birds appear to assess migrant routes and stop over habitats at four major scales; 1) Genetically influenced corridor selection influenced by local weather patterns; 2) large-scale landscape features; 3) Vegetation patches; and 4) microhabitat selection within the vegetation patch. Along the lower Colorado River in Mexico, California and Arizona, and the Santa Cruz and San Pedro rivers in Arizona, these four scales are variously influenced by weather, vegetative species, structure, and plant phenology patterns that appear to provide a cue to insect prey base. In migrating neotropical migrant warblers that we have examined along the Colorado, Santa Cruz and San Pedro rivers, species arrival dates and numbers were variable among years, being largely influenced by plant phenology cycles. Therefore, stopover and bird foraging patterns were greatly influenced by plant species and phenological patterns of the selected microhabitat. It thus appears that large scale landscape features, along with riparian habitat structure, vegetation phenology, and insect prey base all play a role in structuring spring warbler migration patterns along southwestern riparian corridors.

La influencia de la fenología de plantas en aves neotropicales migratorias en el oeste de América del Norte. En el oeste de América del Norte, las rutas de migración de aves terrestres neotropicales evolucionaron en paisajes de elevaciones diferentes y entornos fragmentados y heterogéneos. Las aves terrestres migratorias occidentales parecen evaluar rutas de migración y parar en hábitats en cuatro escalas mayores; 1) selección de corredores por herencia genética influenciados por condiciones del clima local; 2) características mayores del paisaje; 3) manchas de vegetación; y 4) selección de un microhábitat en la mancha de vegetación. En el río Colorado en México, California y Arizona y los ríos Santa Cruz y San Pedro en Arizona, estas cuatro escalas son influenciadas de diversas maneras por el clima, las especies de plantas, la estructura y las condiciones fenológicas de las plantas que parecen proporcionar una señal a los insectos presa. En los chipes neotropicales migratorios estudiados en los ríos Colorado, Santa Cruz y San Pedro, las fechas de llegada de la especie y la cantidad variaron cada año, influenciados principalmente por los ciclos de la fenología de plantas. Por lo tanto, las condiciones del forrajeo y paradas temporales de los pájaros fueron influenciadas principalmente por las especies de plantas y las condiciones fenológicas del microhábitat seleccionado. En consecuencia, parece que las características mayores del paisaje, junto con las estructuras del hábitat ribereño, la fenología de la vegetación y la base de insectos presa todos tienen un efecto en la estructura de las rutas de migración de los chipes de primavera en los corredores ribereños del suroeste.

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Are black bear moving among the mountains in the Sky Islands, Arizona and Northern Mexico? Habitat fragmentation in the sky islands of Arizona and northern Mexico has important implications to the genetic diversity, gene flow, and ultimately the population structure of local taxa. Black bears (*Ursus americanus*) inhabit the sky islands of the Madrean archipelago and are a species of public interest and management focus in the US and of conservation concern in Mexico. We used 10 nuclear DNA (nDNA) microsatellite markers to investigate population structure of black bears in the sky islands of Arizona and northern Mexico. We collected 396 bear samples and used spatial and non-spatial Bayesian assignment models to evaluate nDNA genetic structure and cluster individuals into genetically distinct groups. Subtle population structure was detected indicating high levels of gene flow in recent generations, especially throughout the sky islands region, while lower gene flow was detected between the “mainland” Mazatzal Mountains of Arizona, and the furthest sky islands in northern Mexico, and between the Mazatzal Mountains and the Sierra Madre Occidental, Mexico. The GENELAND, STRUCTURE AND TESS analysis indicated two populations separating the entire sky island region from the Mazatzal Mountains, with an average F_{st} of 0.474 yet connectivity between the two groups was higher with an average F_{st} of 0.07 using these estimators (range = 0.004-0.14). These results indicate that black bears are moving among the sky islands, with distance being the main factor that isolates populations.

¿Se trasladan los osos negros entre sierras de las Islas Serranas de Arizona y el norte de México? La fragmentación del hábitat en las Islas Serranas de Arizona y el norte de México tiene implicaciones importantes en la diversidad genética, el flujo genético, y a lo largo la estructura de la población de los taxones locales. Los osos negros (*Ursus americanus*) habitan las Islas Serranas del archipiélago Madreño y son una especie de interés público y manejo centrado en E.U. y están protegidos en México. Usamos 10 marcadores de microsatélite de ADN del núcleo (nDNA por sus siglas en inglés) para investigar la estructura de la población de oso negro en las Islas Serranas de Arizona y el norte de México. Colectamos 396 muestras de osos y usamos modelos de asignación Bayesianos espaciales y no espaciales para evaluar la estructura genética del nDNA y agrupar individuos en grupos genéticamente distintos. Detectamos estructura sutil de la población que indica niveles altos de flujo genético en generaciones recientes, especialmente en la región de las Islas Serranas, aunque detectamos menos flujo genético entre las montañas “continentales” de Mazatzal de Arizona y las Islas Serranas del norte de México más alejadas, y entre las montañas Mazatzal y la Sierra Madre Occidental, México. Los análisis Geneland, Structure y Tess indicaron dos poblaciones que separan la región entera de las Islas Serranas de la montañas Matzalzal, con un promedio F_{st} de 0.474 pero la conectividad entre los dos grupos fue más alto con un promedio F_{st} de 0.07 usando estos estimadores (intervalo=0.004-0.14). Estos resultados indican que los osos negros se desplazan entre las Islas Serranas, con la distancia siendo el factor principal que aísla las poblaciones.

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Biodiversity and conservation of the Ciénega de Saracachi area, Sonora, México. The Ciénega de Saracachi area, including Arroyos Santo Domingo and Quemado and Rancho la Brisca, is in north-central Sonora (30°22'N 110°25'W; 79 km² area; 960-1,000 m elevation) ca. 100 km south of the Arizona border in the Municipio de Cucurpe. The vegetation is desert grassland on slopes and cottonwood-willow riparian forest in the Ciénega and rocky stream canyons. These upper tributaries of the Río San Miguel are natural corridors on the west side of the Sierras San Antonio and Azul. The high diversity of the area has been recognized since the mid-1970s. In April 2011, a Madrean Archipelago Biodiversity Assessment (MABA) Expedition provided additional species documentation. In the MABA database (www.madreal.org), there are 434 species of plants in 105 families and 271 species of animals in 81 families documented in the area. Invertebrate animals with only 98 taxa in 23 families are very poorly known. Vertebrate animals with 172 species in 58 families are dominated by birds (77.9% of the species). Additional documentation is needed for plants, amphibians, and reptiles (especially snakes) in the summer rainy season, for migratory birds, and for invertebrates and mammals (especially bats) in general. About 10 species of animals are listed as Threatened or Of Special Concern in the NOM-059-SEMARNAT-2010 (the Mexican endangered species law). The La Brisca talussnail (*Sonorella aguafriensis*) is endemic to Arroyo Santo Domingo. Several species of plants and grasshoppers are only known in Sonora from the Ciénega. In 2010, the Saracachi area was nominated to be a Sonoran Área Natural Protegida to preserve its natural values and to develop ecotourism land use options.

Biodiversidad y conservación del área de la Ciénega de Saracachi, Sonora, México. El área de la Ciénega de Saracachi la cual incluye el arroyo Santo Domingo, arroyo el Quemado y rancho la Brisca se localiza en la parte norte centro de Sonora (30°22'N 110°25'W; 79 km² área; 960-1,000 m elevación) ca. de 100 km al sur de la frontera con Arizona en el municipio de Cucurpe. La vegetación es pastizal del desierto en las laderas, y bosques ribereños de álamo y sauce en la ciénega y cañones rocosos de arroyos. Los afluentes altos del río San Miguel son corredores naturales en el occidente de la Sierra San Antonio y de la Sierra Azul. La alta diversidad del área se ha reconocido desde mediados de 1970. En abril de 2011 una expedición del proyecto Evaluación de la Biodiversidad del Archipiélago Madreño (MABA) agregó nuevos registros de especies. En la base de datos de MABA (www.madreal.org), hay 434 especies de plantas en 105 familias y 271 especies de animales en 81 familias documentadas en el área. Los invertebrados con sólo 98 taxones en 23 familias se conocen muy poco. Los vertebrados con 172 especies en 58 familias están dominados por aves (77.9% de las especies). Se necesita documentar más plantas, anfibios y reptiles (en especial serpientes) en la temporada de lluvias del verano, así como aves migratorias e invertebrados y mamíferos (con énfasis en murciélagos) en general. Alrededor de 10 especies de animales están en la lista de la NOM-059-SEMARNAT-2010 con categoría de amenazados o especie en riesgo. El caracol de talud de La Brisca (*Sonorella aguafriensis*) es endémico del arroyo Santo Domingo. Varias especies de plantas y chapulines se conocen en Sonora sólo de la Ciénega. El área de Saracachi se propuso como Área Natural Protegida estatal en 2010 para conservar sus atributos naturales y desarrollar opciones de ecoturismo.

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Examining wildlife responses to phenology and wildfire using a landscape-scale camera trap network. Between 2001 and 2009, the Borderlands Jaguar Detection Project deployed 174 camera traps in the Baboquivari, Sierrita, Tumacacori, Atascosa, Patagonia, and Santa Rita mountains of southern Arizona to record jaguar activity. In addition to the jaguar, these motion-activated cameras, placed along known wildlife travel routes, recorded occurrences of ~ 20 other animal species. We examined relationships of temporal patterns of species observations to landscape phenology and the timing of wildfire events. Landscape phenometrics were derived from time series of monthly Normalized Difference Vegetation Index data from the Moderate Resolution Imaging Spectroradiometer using statistical and curve-fitting techniques. The remote sensing phenometrics were stratified by vegetation type, and analyzed in conjunction with wildlife occurrences by species and camera location. We examined temporal and spatial changes in number of sightings of select species prior to, during, and after three wildfires in the area using fire perimeter data from the **Monitoring Trends in Burn Severity** database. The analyses suggest that phenology and natural disturbance are related to local and landscape-scale dynamics of wildlife in the sky island region; information important for wildlife managers faced with uncertainty regarding changing climate and disturbance regimes.

Análisis de la respuesta de fauna a fenología e incendios forestales mediante el uso de una red de cámaras trampa en un paisaje. Entre 2001 y 2009, el proyecto Borderlands Jaguar Detection colocó 174 cámaras trampa en las cordilleras Baboquivari, Sierrita, Tumacacori, Atascosa, Patagonia y Santa Rita del sureste de Arizona para registrar la actividad de jaguares. Además del jaguar, estas cámaras activadas por movimiento, colocadas en rutas conocidas de fauna, registraron la presencia de otras ~20 especies de animales. Analizamos la relación entre el tiempo de ocurrencia de especies observadas, la fenología del paisaje y el tiempo de incendios forestales. La fenométrica del paisaje se derivó de series de tiempo mensuales de los datos del índice de vegetación de diferencia normalizada tomada del espectroradiómetro de imágenes de media resolución usando técnicas estadísticas y de ajuste de curva. Se estratificó la fenométrica de sensores remotos por tipo de vegetación y se analizó con ocurrencias de fauna por especies y la ubicación de la cámara. Examinamos cambios temporales y espaciales en series de observaciones de ciertas especies antes de, durante y después de tres incendios forestales del área usando datos del perímetro del incendio tomado de la base de datos tendencia del monitoreo en la severidad del incendio. El análisis indica que la fenología y la perturbación natural están relacionadas

con la dinámica local y regional de fauna en la región de las Islas Serranas; información valiosa para los encargados del manejo de fauna que enfrentan incertidumbre con respecto al clima cambiante y regímenes de perturbación.

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Mapping landscape phenology preferences of yellow-billed cuckoo with AVHRR data. We mapped habitat for threatened Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) in the State of Arizona using the temporal greenness dynamics of the landscape, or the landscape phenology. Landscape phenometrics were derived from Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) data for 1998 and 1999 by using Fourier harmonic analysis to analyze the waveform of the annual NDVI profile at each pixel. We modeled the spatial distribution of Yellow-billed Cuckoo habitat by coupling the field data of Cuckoo presence or absence and point-based samples of riparian and cottonwood-willow vegetation types with satellite phenometrics for 1998. Models were validated using field and satellite data collected in 1999. The results indicate that Yellow-billed Cuckoo occupy locations within their preferred habitat that exhibit peak greenness after the start of the summer monsoon and are greener and more dynamic than “average” habitat. Identification of preferred phenotypes within recognized habitat areas can be used to refine habitat models, inform predictions of habitat response to climate change, and suggest adaptation strategies.

Cartografía del paisaje y fenología preferidos del cuco pico amarillo usando datos AVHRR. Elaboramos mapas del hábitat del cuco pico amarillo (*Coccyzus americanus occidentalis*) amenazado en el estado de Arizona con la dinámica temporal verdor del paisaje, o la fenología del paisaje. Los aspectos fenométricos del paisaje se derivaron de los índices de vegetación de diferencia normalizada (NDVI) obtenidos de las imágenes de satélite con sensor AVHRR para 1998 y 1999 mediante el análisis de Fourier para examinar el perfil anual de NDVI en cada píxel. Hemos modelado la distribución espacial del hábitat del cuco pico amarillo al relacionar los datos de campo de presencia o ausencia de cuco y los muestreos de puntos de los tipos de vegetación ribereña y de álamo-sauce con fenométricos del satélite para 1998. Los modelos se corroboraron utilizando los datos de campo y de satélite tomados en 1999. Los resultados indican que el cuco pico amarillo ocupa lugares de su hábitat preferido que exhiben un verdor pico después del comienzo del monzón de verano y son más verdes y más dinámico que el hábitat "promedio". La identificación de fenotipos preferidos en hábitats reconocidos se puede utilizar para mejorar los modelos de hábitat, predecir la respuesta del hábitat al cambio climático y sugerir estrategias de adaptación.

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Lessons learned concerning management and conservation of Sky Island birds on the Northern Jaguar Reserve. The Northern Jaguar Reserve is in the western foothills of the Sierra Madre Occidental and occupies a broad transition zone between Nearctic and Neotropical faunal realms. We assessed the distribution and abundance of birds across all four seasons on the reserve and evaluated conservation and management issues and threats. Since 2007, we have observed 201 species of birds including 130 listed by USFWS as Neotropical migrants, 104 that presumably breed, 20 species of bi-national conservation concern, and a surprisingly large number of species that either winter or breed north of their previously described range limits. Observations suggest the importance of an inland migratory pathway for Neotropical migrants along the Rio Yaqui corridor and indicate the Reserve's value in providing habitat for short-distance migrants that breed in the Sierra Madre and Sky Islands, and long-distance migrants that breed further north. This region faces major conservation challenges including a proposed dam and mining and cattle impacts. Existing conservation programs include land purchase, outreach to neighboring private ranches, habitat restoration, and environmental education. Numerous conservation and management unknowns exist in the Foothills thornscrub and will be discussed.

Lecciones aprendidas sobre manejo y conservación de aves de las Islas Serranas en la Reserva del Jaguar del Norte. La Reserva del Jaguar del Norte se localiza en el piedemonte de la Sierra Madre Occidental y ocupa una zona ancha de transición entre dominios de fauna neártica y neotropical. Evaluamos la distribución y abundancia de aves en las cuatro estaciones en la reserva y analizamos su conservación, manejo y amenazas. Desde 2007, hemos registrado 201 especies de aves incluyendo 130 catalogadas como migratorias neotropicales por el Servicio de Pesca y Vida Silvestre (USFWS por sus siglas en inglés), 104 que se presume se reproducen, 20 especies de importancia para la conservación binacional y una cantidad sorprendente de especies que pasan el invierno o anidan al norte del límite previamente conocido. Las observaciones sugieren la importancia de rutas migratorias del interior para migrantes neotropicales en el corredor del río Yaqui y demuestra el valor de la reserva por ser un hábitat para migrantes de distancias cortas que se reproducen en la Sierra Madre y las Islas Serranas, así como de migrantes de distancias largas que anidan más al norte. Esta región enfrenta enormes retos de conservación, entre ellas la propuesta de una presa, e impactos por la minería y la ganadería. El programa de conservación actual incluye la compra de terrenos, compromisos con ranchos privados adyacentes, restauración del hábitat, y educación ambiental. Se abordarán las numerosas lagunas de conocimiento sobre el manejo y conservación del matorral espinoso de piedemonte.

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Can and when will female jaguars cross the border? Knowledge of the socio-demographics of the northern jaguar and implications for the “jaguar corridor.” A viable population of jaguars in the US cannot be achieved until females migrate across the border or are re-introduced and then encounter an adult male. This talk will present the latest data on social life of the ordinarily considered solitary felid. This includes

marking, home range size, female/male differences, use of mother's home range by young, and movements by age and sex. It will then discuss what is known of the life-history phenomena that help push jaguars to disperse (birth and death rates, age at reproduction, sex ratios, total young per life-time, etc.). The combined socio-demographics will be incorporated into a very simple model and applied to existing knowledge of female geographic distribution to illustrate dispersal scenarios and times to cross into the United States. Implications for conservation and management will be described.

¿Cruzarán la frontera los jaguares hembra? Conocimiento sobre la población del jaguar norteño e implicaciones de “corredores de jaguares.” Una población viable de jaguares en E.U. se logrará hasta que las hembras crucen la frontera o se reintroduzcan y encuentren un macho adulto. Se presentarán los datos más recientes sobre la vida social del que comúnmente se considera un felino solitario. Incluye marcaje, tamaño del territorio, diferencias entre machos y hembras, uso del territorio de la madre por las crías y movimiento por sexo y edad. Después se abordará el fenómeno del ciclo de vida que empuja a que los jaguares se dispersen (tasas de natalidad y mortalidad, edad de reproducción, proporción por sexo, total de crías en su vida, etc.). Los índices demográficos combinados se utilizarán para diseñar un modelo sencillo y se aplicará a la distribución geográfica conocida de hembras para ilustrar escenarios de dispersión y plazos para cruzar a Estados Unidos. Se abordarán las implicaciones de manejo y conservación.

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Understanding and predicting the impact of climate change on hummingbird diversity and migration in the Madrean Archipelago.

Perhaps the greatest threats to hummingbird survival is the effect of changing climates on flowering phenology, where even minor changes in climate can produce large changes in nectar availability and in blooming dates that may decouple the mutualism between hummingbirds and the plants they pollinate. The increasing drought predicted for the Madrean Archipelago could have significant impact on hummingbird diversity in the USA by adversely affecting their nectar resources and thus their ability to migrate through and nest in this area. We are combining time-series data for hummingbirds with climate and remote sensing data to evaluate what changes have occurred in hummingbird populations and to predict future changes. A preliminary data analyses shows a good relationship between MODIS phenology and the abundance of Black-chinned Hummingbirds at a site along Harshaw Creek in the Patagonia Mountains of Arizona. In this paper, we will report on the latest findings of this effort and introduce this new research project funded by NASA through their Biological Response and Climate Change call.

Impacto del cambio climático en la diversidad y migración de colibrís en el Archipiélago Madreño, conocimiento y predicciones. Quizás la mayor amenaza a la supervivencia de los colibrís es el efecto del cambio climático en la fenología floral, donde incluso fluctuaciones menores del clima pueden ocasionar grandes cambios en el néctar disponible y en las fechas de floración que pueden desacoplar el mutualismo entre los colibrís y las plantas que polinizan. Las grandes sequías pronosticadas para el Archipiélago Madreño podrían tener impactos significativos en la diversidad de colibrís en E.U. al afectar negativamente los recursos de néctar y por consiguiente su capacidad para migrar y anidar en el área. Se combinaron los datos de series cronológicas de colibrís con datos de clima y de sensores remotos para evaluar que cambios han ocurrido en las poblaciones de colibrís y predecir cambios futuros. Un análisis preliminar muestra una relación buena entre la fenología MODIS y la abundancia del colibrí barba negra en un sitio de Harshaw Creek en la Sierra Patagonia de Arizona. En esta publicación informaremos sobre los resultados más recientes de este trabajo e introduciremos este nuevo proyecto de investigación financiado por NASA por medio del área de “respuesta biológica y cambio climático”.

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Restoring riparian vegetation for nesting hummingbirds: Is there a conservation dilemma? Hummingbirds, as pollinators, provide important ecosystem services needed for many plants to produce viable seeds and fruit, which then become food resources for many animal species. Building upon the successful efforts by Cuenca Los Ojos to restore the San Bernardino Ciénega and associated riparian zones in northern Sonora, we investigated if this restored habitat provided the resources needed for successful nesting by hummingbirds by comparing it with a Sonoita Creek/Patagonia Lake site known to be used successfully by nesting Black-chinned and Broad-billed Hummingbirds. We conducted point counts and nest searches to detect hummingbird abundance and richness and counted floral resources used by hummingbirds. During late May, floral resources were similar at both sites but by mid-June, the only reliable nectar resource was tree tobacco (*Nicotiana glauca*) at Sonoita Creek. During May, three nests were found at San Bernardino but none remained active in June. At Sonoita Creek, nesting continued throughout the censuses with 72 nests found. Viable nectar resources likely limits the ability of hummingbirds to nest in restored riparian habitats at San Bernardino but Tree Tobacco, considered by many to be an invasive species, may not be the best option for restoring the nectar landscape.

Restauración de la vegetación ribereña para la anidación de colibrís, ¿un dilema de conservación? Los colibrís, como polinizadores, aportan servicios ecosistémicos necesarios para que muchas plantas produzcan semillas viables y frutos que después se convierten en recursos alimenticios de especies animales. Partiendo del trabajo exitoso de Cuenca los Ojos de restauración de la ciénega San Bernardino y las zonas ribereñas asociadas en el norte de Sonora, investigamos si este hábitat restaurado contaba con los recursos necesarios para la anidación exitosa de colibrís al compararlo con un sitio de Sonoita Creek y Patagonia Lake conocido como área de anidación exitosa de dos especies de colibrís, *Archilochus alexandri* y *Cynanthus latirostris*. Se realizaron muestreos mediante transectos de conteo y búsquedas de nidos para determinar la abundancia y diversidad de colibrís y contamos los recursos florales usados por los colibrís. A finales de mayo, los recursos florales fueron similares en ambos sitios, pero a mediados de junio, el único recurso fiable de néctar fue el juan loco (*Nicotiana glauca*) en Sonoita Creek. En mayo, se encontraron tres nidos en San Bernardino pero ninguno estaba activo en junio. En Sonoita Creek, la anidación continuó durante el censo, encontrándose 72 nidos. Recursos viables de néctar probablemente limitan la capacidad de anidación del colibrí en los hábitats ribereños restaurados de San Bernardino pero el juan loco considerado por muchos como una especie invasora, quizás no sea la mejor opción para restaurar el paisaje del néctar.

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Municipal effluent: a viable source for environmental flows? Many human actions have altered the hydrological processes that shape riparian ecosystems. One change, the release of treated wastewater into waterways, has created perennial base flows and increased nutrient availability in ephemeral or intermittent channels. While there are benefits to utilizing treated wastewater for environmental flows, there are numerous unresolved ecohydrological issues. Here we summarize results of empirical research addressing several aspects of this topic. A statewide spatial analysis of patterns of effluent generation and release was conducted, revealing that hydrogeomorphic setting influences downstream riparian response. A field study documented differences in vegetation structure between two effluent-dominated reaches of the Santa Cruz River and a control river (the San Pedro). Third, a greenhouse study indicated that varying concentrations of nitrogen and phosphorus, emulating levels in effluent, influenced composition, biomass, and richness of herbaceous plant communities. We conclude that water quantity and water quality both affect riparian ecosystem development following discharge of effluent into semiarid region streams, with these effects mediated by the hydrogeomorphic context of the receiving stream. If effluent is to be used for environmental flows, ecological data generated by this and other studies needs to be integrated into water resource management decision frameworks.

Aguas residuales municipales, ¿una fuente viable para corrientes ambientales? Muchas actividades humanas han alterado los procesos hidrológicos que forman los ecosistemas ribereños. Un cambio, la liberación de aguas residuales tratadas en cauces de arroyos, ha creado corrientes perennes y ha aumentado los nutrientes disponibles en riachuelos efímeros o intermitentes. Aunque hay beneficios al utilizar el agua residual tratada para corrientes ambientales, hay varios problemas ecohidrológicos que no se han resuelto. Aquí resumimos los resultados de la investigación empírica abordando varios aspectos de este tema. Se llevó a cabo un análisis espacial del origen y liberación de las aguas residuales, revelando que el marco hidrogeomórfico influye la reacción del río abajo. Un trabajo de campo documentó las diferencias de la estructura de la vegetación entre dos tramos dominados por aguas residuales del río Santa Cruz y un río de control (el San Pedro). Tercero, un estudio de un invernadero indicó que concentraciones variables de nitrógeno y fósforo, emulando los niveles en aguas residuales, influyeron la composición, la biomasa y la diversidad de plantas herbáceas. Concluimos que tanto la calidad como la cantidad de agua afectan el desarrollo del ecosistema ribereño después de la descarga de aguas residuales en arroyos de regiones semiáridas, con estos efectos influidos por el contexto hidrogeomórfico de los arroyos que las reciben. Si el agua residual se usa para corrientes ambientales, los datos ecológicos generados por este y otros estudios necesitan integrarse al manejo de los recursos del agua.

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Pinaleño LiDAR: Evaluating forest health and landscape factors Changes in forest conditions have led to large and severe wildfires and devastating insect outbreaks in the Pinaleño Mountains of Southeastern Arizona. The risk of additional wildfires and insect outbreaks have prompted restoration efforts to reduce further threats to forest resilience and provide habitat sustainability for the Mount Graham red squirrel (MGRS) (*Tamiasciurus hudsonicus grahamensis*), a federally listed endangered species. Airborne Laser Scanning or LiDAR is a cost effective means to gather forest structure and biomass information for project planning, implementation and monitoring in remote mountainous terrain. The Coronado N.F. collected LiDAR data in September 2008 over 85,518 acres to provide current, detailed information on forest structure and fuels. The derived information is being used to plan, implement, and monitor ecosystem restoration projects and assist in creating a MGRS habitat model. The LiDAR data has provided continuous non-discrete forest inventory data; mapping of forest biomass, canopy fuel, and forest structure characteristics; mapping of old growth mixed-conifer (a key MGRS habitat); mapping of recent insect and fire disturbances; and collection of forest inventory data in locations where data is difficult to obtain by traditional forest inventory methods.

Pinaleño LiDAR: Evaluación del equilibrio ecológico del bosque y factores del paisaje. Cambios en las condiciones del bosque han causado incendios forestales severos y plagas de insectos devastadoras en las montañas Pinaleño del sureste de Arizona. El riesgo de más incendios y plagas ha motivado esfuerzos de restauración para reducir nuevas amenazas a la resistencia del bosque y proporcionar sostenibilidad del hábitat de la ardilla roja de Mount Graham (MGRS por sus siglas en inglés, *Tamiasciurus hudsonicus grahamensis*), especie en peligro de extinción en

la norma federal. La detección de rayos láser por sensores remotos o LiDAR (por sus siglas en inglés) en una manera rentable de acumular información sobre la estructura y biomasa del bosque para usarse en la planificación de proyectos y el monitoreo de terrenos remotos montañosos. En el Bosque Nacional de Coronado, se colectaron datos de LiDAR en septiembre de 2008 en más de 34,400 hectáreas para tener información actual detallada sobre la estructura del bosque y vegetación combustible. La información derivada se está usando para planificar, implementar y monitorear proyectos de restauración del ecosistema y para crear un modelo del hábitat de la MGRS. La información de LiDAR ha proporcionado datos de inventario del bosque continuos; mapas de la biomasa forestal, combustible de las copas y características de la estructura del bosque; mapas de bosques mixto de coníferas antiguos (un hábitat clave para la MGRS); mapas de plagas e incendios recientes; y recolección de datos de inventario forestal en lugares donde es difícil la toma de datos por métodos tradicionales.

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Promoting non-charismatic microfauna: artist and scientists join forces to document moth diversity in the Madrean region. Joseph Scheer is an artist who for the past 15 years has been using scanning technology to create images of small biological subjects, primarily moths. Finished prints of phenomenal clarity of up to eight feet in expanse are produced from subjects of sometimes only a few millimeters in size. These images have generated great interest in the scientific community and it was inevitable that this work would involve the science of the subjects themselves. Mr. Scheer has teamed with researchers and students in the USA and Mexico to document the moth diversity of the Mexican state of Sonora and has returned from a year's stay in the state as a Fulbright fellow. This endeavor furthers Mr. Scheer's artistic practice, but is also being conducted in a way that is generating enormous amounts of scientifically valuable information. Furthermore, art's ability to reach and inspire the public furnishes influential means of raising awareness of science, biodiversity and conservation; in this case on behalf of organisms that for one reason or another are not considered "charismatic."

Promoviendo la microfauna no carismática: Artistas y científicos se unen para documentar la diversidad de palomillas en la región Madreña. Joseph Scheer es un artista que los últimos 15 años ha usado tecnología de escáners para crear imágenes de sujetos biológicos pequeños, ante todo, palomillas. Se producen imágenes claras de hasta 2.4 m de extensión de sujetos que a veces miden tan sólo milímetros. Estas imágenes han generado mucho interés en la comunidad científica y era inevitable que esta obra involucrara la ciencia de los sujetos mismos. Scheer se ha asociado con investigadores y estudiantes de E.U. y México para documentar la diversidad de palomillas en el estado mexicano de Sonora y ha terminado una estancia de un año en el estado como becario Fulbright. Este esfuerzo no sólo promueve la práctica artística de Scheer, también se conduce de una manera que genera enormes cantidades de información científica importante. Además, la capacidad del arte de tocar e inspirar al público proporciona maneras de crear conciencia de las ciencias, la biodiversidad y la conservación; en este caso sobre organismos, que por una razón u otra, no se consideran "carismáticos".

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The Southwest Fire Science Consortium: A new opportunity in fire science and management. The Southwest is one of the most fire-dominated regions of the US. Currently, in the Southwest, there are several localized efforts to develop fire science information and to disseminate it to practitioners on the ground in a practical manner. However, many of these efforts are moving in parallel, without thoughtful interaction among projects. Managers and scientists are often not aware of each other or of the external resources available. A consortium is needed to bring these parallel efforts together to be more efficient and inclusive, allowing future fire science issues to be addressed from a broader perspective with more information, more partners, and more resources. With support from the Joint Fire Science Program (JFSP), we have initiated the Southwest Fire Science Consortium to promote communication and meet fire knowledge needs of scientists and managers. We have organized the Southwestern Fire Science Consortium around three key questions: (1) What do people need to know? Information needs are assessed through workshops, surveys, and organization of a community of practice of wildland fire professionals; (2) What information is already known? Synthesis of existing science; and (3) What are the key information gaps between what we need to know and what is already known? This question leads to the identification of critical areas for new research and management experiments. By focusing on these key questions we hope to provide a mechanism for managers, scientists, and policy makers to interact and share science in ways that can effectively move new information to management practices and facilitate new research based on management needs.

El Consorcio Suroeste de la Ciencia de Incendios: Una nueva oportunidad en la ciencia y manejo de incendios. El Suroeste de E.U. es una de las regiones más afectadas por los incendios. Actualmente en el Suroeste, hay esfuerzos localizados para desarrollar información sobre la ciencia de los incendios y difundirla a facultativos del terreno de una manera práctica. Sin embargo, muchos de estos esfuerzos están moviéndose paralelamente, sin interacción atenta entre proyectos. Los administradores y científicos casi nunca son conscientes el uno del otro o de los recursos disponibles. Se necesita un consorcio para juntar estos esfuerzos paralelos para ser más eficaz e inclusivo, y permitir que se discutan problemas de la ciencia de incendios futuros con una perspectiva amplia, más información, más socios y más recursos. Con el apoyo del programa conjunto de las ciencias de incendios (JFSP por sus siglas en inglés), hemos empezado el Consorcio Suroeste de las Ciencias de Incendios para promover la comunicación y enfrentar las necesidades de los administradores y los científicos. Hemos organizado el Consorcio Suroeste de las Ciencias de Incendios alrededor de estas preguntas claves: (1) ¿Qué es lo que debería saber la gente? Se evalúa la necesidad

de información a través de talleres, estudios y la organización de una comunidad de práctica de profesionales de los incendios forestales; (2) ¿Qué información ya se sabe? La síntesis de la ciencia actual; y (3) ¿Cuáles son las lagunas de información claves entre lo que se debería saber y lo que ya se sabe? Esta pregunta lleva a la identificación de áreas críticas de nueva investigación y experimentos de manejo. Al centrarnos en estas preguntas claves esperamos proporcionar un mecanismo para que los administradores, científicos y los que se encargan de formular leyes interactúen y compartan la ciencia de manera que puedan convertir la información nueva en prácticas de manejo y facilitar nuevos estudios basados en las necesidades de manejo.

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Post-wildfire erosion in the Chiricahua Mountains. The Horseshoe 2 Fire burned 90,226 ha (222,954 ac) of the Chiricahua Mountains in the Coronado National Forest of southeast Arizona from May 8 to June 25, 2011. This mountain range in the Madrean Archipelago has been burned by widespread fires prior to 1890, numerous small fires since 1890, and a more recent 11,129 ha (27,500 ac) Rattlesnake Fire in 1994. The latter fire resulted in significant erosion during post-fire Monsoon storms that eroded deep gullies (~10 m) in Ward Canyon (upper West Turkey Creek), and deposited large amounts of sediment in lower channels, particularly in Rucker Creek and in Rucker Lake. The Horseshoe 2 Fire burned approximately 70% of the mountain range with a mosaic of fire severities. Post-fire erosion from floods and debris flows produced additional erosion and sedimentation that is currently being evaluated through fieldwork and repeat aerial photography. This paper discusses the magnitude of post-fire erosion and the impacts on channel systems in the Chiricahua Mountains.

La erosión después de incendios en la sierra de Chiricahua. El incendio Horseshoe 2 quemó 90,226 ha de la sierra de Chiricahua en el Bosque Nacional Coronado en el sureste de Arizona desde el 8 de mayo hasta el 25 de junio de 2011. Esta cordillera del Archipiélago Madreño se ha quemado con incendios generalizados desde antes de 1890, numerosos fuegos pequeños después de 1890 y más recientemente el incendio de Rattlesnake de 1994 que quemó 11,129 ha. El fuego más reciente ocasionó una erosión significativa durante las tormentas del monzón después del incendio que erosionó barrancos profundos (~10 m) en Ward Canyon (parte alta del río West Turkey Creek) y depositó grandes cantidades de sedimento en los cauces bajos, especialmente en Rucker Creek y en Rucker Lake. El incendio de Horseshoe 2 quemó aproximadamente 70% de la sierra creando un mosaico con diferente intensidad del fuego. La erosión después del incendio, causada por inundaciones y deslaves, produjo erosión y sedimentación adicional que actualmente se está evaluando mediante trabajo de campo y fotografía aérea repetida. Este trabajo discute la magnitud de la erosión que ocurre después de los incendios y el impacto en el sistema de cauces de la sierra de Chiricahua.

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Population viability of Mexican wolf (*Canis lupus baileyi*) in northeastern Sonora, Mexico The Mexican Wolf (*Canis lupus baileyi*) is considered extinct in Mexico. Population viability analyses (PVA), was performed to evaluate the risk of extinction of a reintroduced population of five Mexican wolves. Other PVAs developed, lack demographic data of free-ranging populations, resulting in unreliable models for the development of appropriate management strategies. We developed an AVP for wolves to be released in Mexico, with demographic parameters of the reintroduced population in the United States to serve as a tool for management of wolves in Mexico. The demographic parameters were obtained from reports from 1999 to 2009. Subsequently we evaluated the population dynamics under different scenarios. It was found that high adult mortality due to social conflicts is the demographic factor that affects population growth. The scenario in establishing a viable population of Mexican wolves in Mexico requires reducing mortality rates (20%) and supplementation of two breeding individuals in the first 10 years after the initial release to withstand more than 50 wolves. It is necessary to improve the social perception of the wolf in the region and educate people about livestock management practices that avoid conflict with predators, because an antagonistic attitude may limit the establishment of a viable population.

Viabilidad de la población del lobo mexicano en el noreste de Sonora, México. El lobo mexicano (*Canis lupus baileyi*) se considera extinto en México. Se hizo un análisis de viabilidad de población (PVA por sus siglas en inglés) para evaluar el riesgo de extinción de la población reintroducida con cinco lobos. Previos PVAs no tienen datos demográficos de poblaciones libres, resultando en modelos poco fiables para el desarrollo de estrategias de manejo adecuadas. Realizamos un AVP de los lobos a liberarse en México, con parámetros demográficos de la población reintroducida en Estados Unidos como referencia para el manejo de lobos en México. Los parámetros demográficos se tomaron de informes de 1999 a 2009. Posteriormente se evaluó la dinámica de población bajo diferentes escenarios. La alta mortalidad de adultos por conflictos sociales es el factor demográfico principal que afecta el crecimiento de la población. Para establecer una población viable del lobo mexicano en México se requiere reducir las tasas de mortalidad al 20% y agregar dos individuos en edad reproductiva los primeros 10 años después de la liberación inicial para mantener más de 50 lobos. Es necesario mejorar la percepción social del lobo en la región y educar a la gente sobre prácticas de manejo de ganado para evitar conflictos con depredadores, ya que una actitud antagónica no permitirá el establecimiento de una población viable.

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The small mammal community at preserved and disturbed habitats in the Sierra San Luis, Sonora, Mexico. Species richness and community structure of small mammals has proven an effective method to determine the stability or disturbance between environments. Our aim was to determine the structure of small mammals at grasslands and scrubland, both conserved or fire affected at the Sierra San Luis during 2011. We used Sherman traps placed along sixteen transects to assess richness and diversity. Shannon diversity was higher for conserved scrubland ($H' = 1.67$) and grassland ($H' = 0.70$) without fires. The most abundant species were *Peromyscus eremicus*, *P. boylii* and *Neotoma albigula*, occurred at the scrubland. Jaccard diversity generated two groups with a similarity of 33% and a correlation coefficient of 0.85. Although there is not a high turnover rate between habitats, there is a trend to have abundant generalist species at sites in response to fire.

Comunidad de mamíferos pequeños en hábitats conservados y modificados en la Sierra San Luis, Sonora, México. La riqueza de especies y la estructura de comunidades de mamíferos pequeños ha demostrado ser un método efectivo para determinar la estabilidad y el disturbio del entorno. Nuestro objetivo fue determinar la estructura de la comunidad de mamíferos pequeños del pastizal y matorral, tanto conservados como afectados por incendios, en la Sierra San Luis durante el 2011. Usamos trampas Sherman ubicadas en 16 transectos para evaluar la riqueza y diversidad. La diversidad de Shannon fue mayor en los matorrales conservados ($H' = 1.67$) y pastizal sin incendios ($H' = 0.70$). Las especies más abundantes fueron *Peromyscus eremicus*, *P. boylii* y *Neotoma albigula* en el matorral. La diversidad de Jaccard generó dos grupos con una semejanza de 33% y el coeficiente de correlación de 0.85. Aunque no se registró un volumen alto entre hábitats, hay una tendencia a tener especies generalistas abundantes en los sitios quemados.

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Drought decreases survival of Sonoran desert tortoises in Arizona. Decisions relevant to conservation of rare and threatened species can be hampered by our inability to differentiate between short-term, local fluctuations in population attributes and long-term, widespread declines that can affect persistence. We used 22 years of capture-recapture data for Sonoran desert tortoises (*Gopherus agassizii*) collected from 15 locations across their geographic range in Arizona to evaluate environmental factors associated with spatial and temporal variation in adult survival. Rates of annual survival were generally high (mean = 0.92, SE = 0.01), as expected for a long-lived species, but decreased with proximity to human habitation. Survival of adults also varied markedly in response to drought; when drought severity was high, survival of tortoises was reduced, particularly in the most arid parts of their range. In three well-studied populations, survival of adults was markedly lower during one survey interval (0.77-0.81) than all other intervals (0.93-0.98); these periods of reduced survival coincided with periods of extreme drought. If drought frequency or severity increases as predicted by several climate-change models, recovery and persistence of tortoise populations in this region could be affected adversely.

La sequía disminuye la supervivencia de la tortuga del desierto Sonorense en Arizona. Las decisiones importantes de conservación de especies raras o amenazadas pueden dificultarse por nuestra incapacidad para diferenciar entre variaciones locales por períodos cortos de los atributos de la población, y bajas generalizadas a largo plazo que pueden afectar su persistencia. Usamos 22 años de datos de captura y recaptura de la tortuga del desierto Sonorense (*Gopherus agassizii*) colectados en 15 lugares de su rango geográfico en Arizona, para evaluar los factores ambientales asociados con la variación espacial y temporal en la supervivencia de adultos. Las tasas anuales de supervivencia en general fueron altas (media = 0.92, SE = 0.01), como se espera en especies de vida larga, pero disminuyen cerca de habitaciones humanas. La supervivencia de adultos también varió notablemente en respuesta a sequías; cuando la intensidad de la sequía fue alta, la supervivencia de la tortuga disminuyó, particularmente en las partes más áridas de su rango. En tres poblaciones bien estudiadas, la supervivencia de adultos fue notablemente más baja durante un intervalo del estudio (0.77-0.81) que todos los otros intervalos (0.93-0.98); estos períodos de supervivencia reducida coincidieron con períodos de sequía extrema. Si aumenta la frecuencia o la severidad de las sequías como predicen los modelos de cambio climático, se puede afectar negativamente la recuperación y la persistencia de la población de tortuga en esta región.

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