Sonorensis

Arizona-Sonora Desert Museum

In gratitude for your support of the Arizona-Sonora Desert Museum

CELEBRATING THE *Sky* ISLANDS

2013

Sonorensis

Arizona-Sonora Desert Museum

Volume 33, Number 1
Winter 2013
The Arizona-Sonora Desert Museum
Co-founded in 1952 by
Arthur N. Pack and William H. Carr

Craig Ivanyi
Executive Director

Debra Colodner
Director, Conservation Education and Science Department

Nancy Serensky
Production Manager

Clare Aslan and Kim Franklin
Managing Editors

Linda Brewer
Contributing Editor

Martina Clary
Design and Production

Sonorensis is published as a benefit to the Arizona-Sonora Desert Museum membership as a resource for furthering understanding of the Sonoran Desert Region. 2021 N. Kinney Road, Tucson, Arizona 85743.

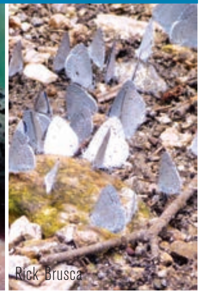
Visit us at www.desertmuseum.org

Cover: Mt. Lemmon sunrise. Howard Paley

Back cover: Wilderness of Rocks, Catalina Mountains. Steve Franks

Thanks to all the photographers and organizations who contributed photos for this issue of Sonorensis.

Photos on this page, above: Dew on leaf; Western Hercules beetle (a rhinoceros beetle); spring azure butterflies ponding.

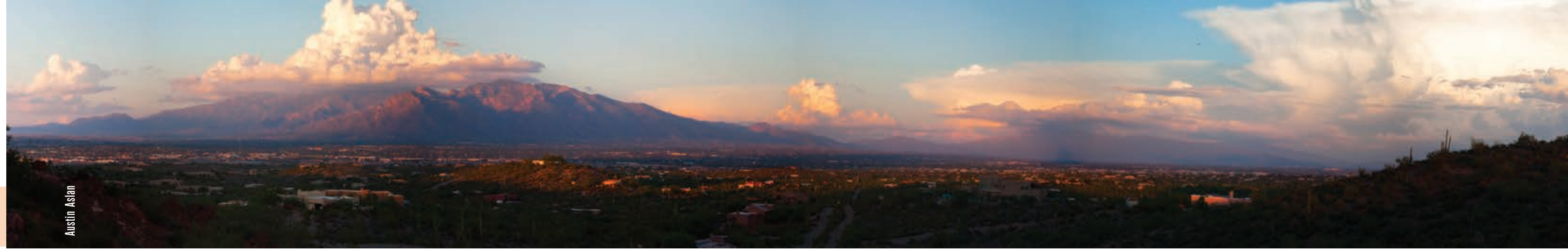


CONTENTS

Celebrating THE SKY ISLANDS

Introduction

Clare Aslan, Ph.D.
Conservation Research Scientist,
Arizona-Sonora Desert Museum



Above: View of Tucson basin with Catalina Mountains and Rincon Mountains in the background. Below right: Map based on cartographic GIS research by Joel Viers/Lirica.

Twelve thousand years ago, prehistoric horses and grizzly bears wandered oak woodland where the city of Tucson, Arizona, now sits. Sloths roamed in continuous forests and woodlands from the Rocky Mountains in Colorado to the Sierra Madre Occidental in Sonora, Mexico. Mighty glaciers covered much of the North American Continent. Average global temperatures were several degrees lower than they are today.

About 11,000 years ago, things began to change. Global temperatures began to rise. Plant communities responded, shifting northward or moving up mountain slopes as they tracked their ideal temperature bands. In what is now southern Arizona and northwest Mexico, a vast desert began to assemble as new species moved into the area from the south.

In the middle of that emerging desert, high mountain ranges punctuated the land in a rumpled north-south swath like an untidy blanket. As temperatures rose, desert vegetation filled the valleys like a sea flooding lowlands between mountain peaks, leaving oak woodland and higher, conifer-dominated habitats intact but isolated on mountain ranges separated by up to hundreds of miles. These isolated peaks have come to be known as the "Sky Islands," or "Madrean Sky Islands," or "the Madrean Archipelago."

Today, our Sky Islands are home to many animals and plants whose ancestors originated in the Rockies or the Sierra Madre. Essential breeding habitat for species such as the Arizona tree frog (*Hyla wrightorum*—our state amphibian) and Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*), as well as oases for countless migrating birds, they are also welcome retreat and recreation for city dwellers escaping the triple-digit, low-desert days of summer, for children playing in snow, and for those simply seeking refreshment on a woodland trail. To imagine Tucson without its ring of dramatic mountains, topped in the summer with billowing monsoon clouds, is to imagine a muted city. Yet, the importance of the Sky Islands goes deeper than aesthetic and recreational delights. These mountain ranges capture moisture from the atmosphere and generate rain that is the desert's lifeblood. The topographical complexity and geographical placement of the Sky Islands begets the Sonoran Desert's remarkable biodiversity. This diversity, in turn, is a key to ecosystem services like clean air, clean water, aquifer recharge, and other natural processes critical to the health and well-being of humans.

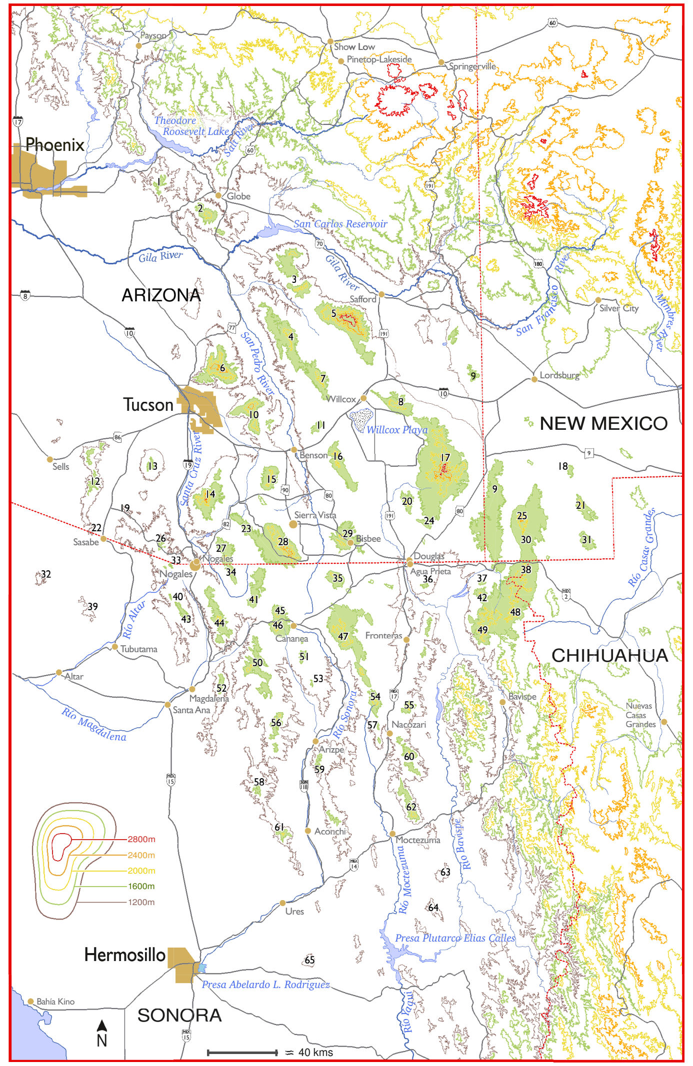
With their wide range of habitats, the Sky Islands of southeastern Arizona host species that draw from all directions, elevations, and latitudes. The Rocky Mountains, Great Plains, Chihuahuan Desert, Sonoran Desert, and Sierra Madre Occidental converge here, leading to an astonishing diversity of mammal and reptile species. More than 450 bird species (nearly half of all those found in the United States) occur here, along with more than 3,000 species of plants. The Sky Island Region has also been identified as the center of bee and ant diversity on this continent.

In its quest to foster understanding and appreciation of the Sonoran Desert Region, the Arizona-Sonora Desert Museum has long showcased and studied Sky Island habitats. To construct our Mountain Woodland exhibit, Museum botanists explored the high elevations of the Santa Catalina Mountains, selecting plant species that would convey the mountain experience to our visitors. In the 1980s and 90s, Museum researchers (particularly Dr. Tom Van Devender, now with the Sky Island Alliance) analyzed detritus from ancient packrat middens for groundbreaking research on the deep biotic history of this region. Currently, Museum scientists are generating the first species lists of arthropods for target Sky Islands, tracking bat distributions across the Sky Islands of southeastern Arizona, identifying pollinators of threatened plant species, and documenting range shifts of montane plants tied to climate change. The Museum also prioritizes the conservation of Sky Island habitats and serves as refuge for several threatened and endangered montane species. Today, the most significant threats to Sky Island ecosystems are accelerating climate change (which may well drive high-elevation species off the mountaintops, and contributes to extensive insect outbreaks and high-intensity wildfires) and development in the valleys (which often cuts off vital connections between wildlife populations). By studying and understanding these ecosystems, we are better equipped to conserve them.

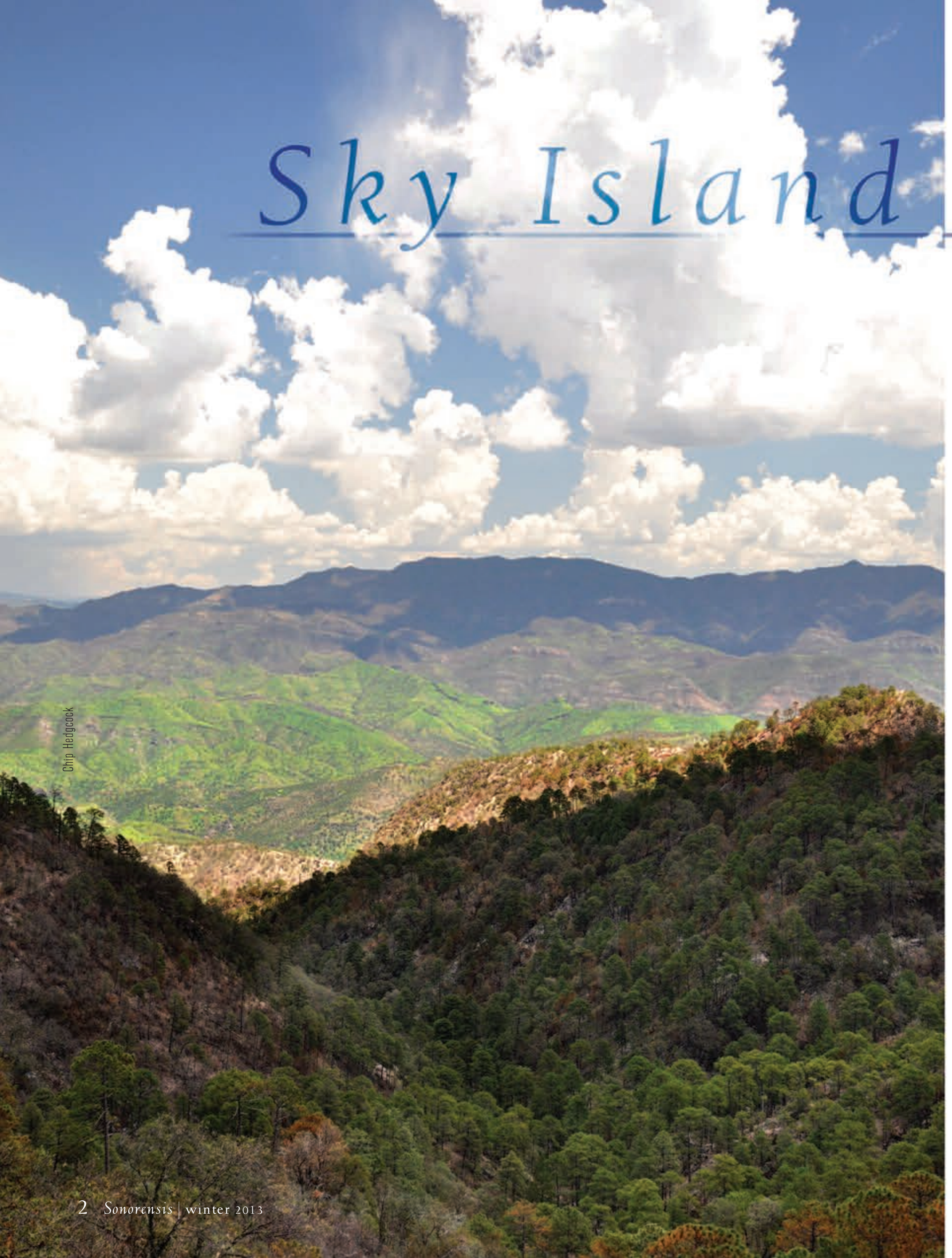
In this issue of *Sonorensis*, we celebrate the Sky Islands as troves of biodiversity, central to our experience of living in and with the Sonoran Desert. We also celebrate the community of scientists, conservationists, and land managers working to protect them. S

SKY ISLAND ARCHIPELAGO

1 Superstition Mountains
2 **Pinal Mountains**
3 Santa Teresa Mountains
4 Galiuro Mountains
5 Pinaleño Mountains
6 **Santa Catalina Mountains**
7 Winchester Mountains
8 **Dos Cabezas Mountains**
9 Peloncillo Mountains
10 Rincon Mountains
11 Little Dragoon Mountains
12 Baboquivari Mountains
13 Sierrita Mountains
14 Santa Rita Mountains
15 Whetstone Mountains
16 Dragoon 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



© 2012 Wendy Moore



Chip Hedgcock

Sky Island GEOLOGY

Debbie Colodner, Ph.D.
Director, Conservation Education and Science,
Arizona-Sonora Desert Museum

On the timescale of mere mortals, geology is the stage on which the drama of life unfolds. But speed up time, and geology takes center stage as mind-boggling forces shape the Earth like putty. About 70 million years ago, the Sky Island Region was part of a great rising mountain range, as the western edge of North America crumpled, cracked, and folded under pressure from a collision with a crustal plate to the west. Then, in a huge plot reversal, the pressure was suddenly off, and the region started to stretch, heated by geological processes below. From 25 to 12 million years ago this land was pulled slowly apart like taffy, creating much of our topography. The final bit of stretching, from 12 to 4 million years ago, cracked the crust, forming the mountains and valleys we see today. These events shaped the broad region known as the Basin and Range Geologic Province, which stretches from northern Mexico all the way to southern Oregon and Idaho. The Sky Islands were formed in the southern part of the province, between the Rocky Mountains to the north and the Sierra Madre Occidental to the south, in a vast gap between those higher-elevation ranges.

The mountains of the Sky Islands rise thousands of feet above the low valley floors, punching into layers of atmosphere that are cooler and wetter. As winds force air up and over these mountains, water vapor condenses, forming clouds, and when we are lucky, rain. Thus, the mountains help pull water from the air and bring it back to the landscape, where it nourishes life in the Sky Islands and the valleys below, and seeps into aquifers that supply riparian areas as well as a multitude of human needs. S

Left: Sierra Bacadéhuachi

On the Trail of Bats IN THE SKY ISLANDS OF SOUTHEASTERN ARIZONA

Karen Krebbs
Conservation Biologist

As we sit quietly beside a stream in the Galiuro Mountains, a scream shatters the cool evening and bounces off the canyon walls. My assistant turns to me. "Do we have anything to worry about?" I smile and answer, "It's just an angry mountain lion and will probably move on," as I strain my eyes to locate the animal, which sounds very close. After all, we had set a net over a large pool of water to capture bats, and the big cat is probably thirsty.

Bruce Taubert

I often think about the mountains lions, black bears, skunks, snakes, Gila monsters, owls, deer, and other wildlife that have contributed to the excitement of my field research in the Sky Islands these last fifteen years. There was a time in the Pinaleño Mountains, when I woke up in the middle of the night to find a skunk had placed its front legs on my cot just inches from my face! On another occasion, a skunk jumped up on my cot and landed on my chest as I was sleeping. I slowly put my head back down and went back to sleep; I didn't want to make any sudden movements. But there is nothing that will get your heart pounding faster than a rattlesnake that settles under your old, torn lawn chair. The snake *under my chair* definitely wasn't there when I set it up!

Through the years, I have utilized mist nets, acoustic recording equipment, video cameras, and infrared lights to capture and detect bats along streams, trails, meadows, washes, hilltops, and in caves and mines. My fieldwork has produced data on more than 3,500 bats representing 30 species in Arizona and Mexico, and information on 2,800 of those bats (22 species) comes from the mountains of southeastern Arizona. All of these field data—including measurements for forearms, fingers, thumbs, ears, feet, and weight—are provided to state and federal partners such as Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and the National Park Service, and the data have produced valuable information about the migration, movements, and reproduction of wild bats, as well as their responses to weather extremes, their general health, and information specific to local populations.

Years of annual fieldwork in the Chiricahua Mountains have provided important data on the arrival times of migratory bats. We have learned that silver-haired bats *(Lasionycteris noctivagans)* do not arrive at the same time each year. In fact, we suspect that some individuals may actually be year-round residents of the mountains in this area, since I have captured this species repeatedly in both summer and winter in the Chiricahuas. But far more silver-haired bats are captured during the summer months than in the winter, suggesting both resident and migratory behaviors. Typically, this species is captured between three and four hours after sunset, but for the past several years I have observed this bat foraging during daylight hours, another exciting

Courtesy of Karen Krebbs

Bruce Taubert

Top above: Karen Krebbs using telemetry antennas to detect bats.
Cut out left: Allen's lappet-browed bat *(Idionycteris phyllotis)*.
Above: Townsend's big-eared bat *(Corynorhinus townsendii)*.

Karen Krebbs

Above: Mexican spotted owl *(Strix occidentalis lucida)*.
Below: Hooded skunk *(Mephitis macroura)*.
Cut out right: Silver-haired bat *(Lasionycteris noctivagans)*.

Bruce Taubert

and unexpected discovery, since bats are more vulnerable to predators during daylight hours.

In twilight and dark hours, owls may be the most common predator of bats as they forage. Bat bones are commonly found in owl pellets, and I have captured owls and bats simultaneously in my nets—a fair indication that the owl was chasing the bat when they were captured. Some owl species roost in the very same caves and mines as many bat species. At one of my study sites in the Chiricahuas, a Mexican spotted owl *(Strix occidentalis lucida)* shows up regularly to watch us capture, process, and release bats, but this owl has never chased any of the bats we have processed; it just sits quietly and watches. Although bats are generally considered prey for this species, this individual appears to be more interested in watching *us* capture bats than in catching one itself.

WINTER BATS

Most bat research is carried out during the summer months, but winter work is just as rewarding, and has provided important data on bat behavior in cold temperatures. My winter work in the Chiricahuas has revealed that not only silver-haired bats, but many species of bats remain active throughout the winter, and, although some individuals of these species may disappear during periods of extreme cold temperatures, they reemerge when weather conditions improve. During cold winter evenings, I have used a bat detector to record feeding buzzes (short, rapid, high-pitched ultrasonic pulses emitted by echolocating bats during the final stages of capturing prey). These recordings demonstrate that the bats are actively hunting during the winter (which leads me to wonder about the insects that must also be active in these cold temperatures). One evening I captured a female pallid bat *(Antrozous pallidus)* that was active while the temperature was only 24° Fahrenheit! But add wind and moisture to the weather equation, and the bats will opt not to come out!

One cold November evening, I captured two males, a Townsend's big-eared bat *(Corynorhinus townsendii)* and an Allen's lappet-browed bat *(Idionycteris phyllotis)*, at the same time in the same net pocket. We processed the bats and released both at the same time; they flew off in the same direction. This was only the sixth time I had captured an Allen's lappet-browed bat in 14 years of fieldwork, and I have never captured this species together with another species, which led me to wonder about the possible reasons these bats were flying together that evening. Although extending fieldwork into the winter months has revealed exciting new information about the behavior of insectivorous bats, it has also generated many new questions that remain to be answered.

Following the trail of bats in 12 different Sky Islands has been extremely rewarding. I eagerly look forward to each and every field day, and I am still hopeful that during one of my field research trips, I will spot an elusive jaguar watching me work along some mountain stream! S

Bill Hornbaker

SUGGESTED READING

Kunz, Thomas H. 2010. *Field Guide to the Bats of North America.* Oxford University Press, USA.

Sonorensis: Celebrating Bats. 2011. Arizona-Sonora Desert Museum, Tucson, AZ.

Into the MEXICAN SKY ISLANDS

Sky Jacobs
Watershed Management Group

A monsoon storm drenches a brown-backed solitaire on the east slope of a high sierra. A mountain creek trickles softly over worn rocks. A land snail slides across moist leaf litter on a forest floor. Countless moments of nature's poetry go unsung every minute of every day in the remote parts of the Madrean Sky Islands.

Within the United States, the Madrean Sky Islands are largely public lands that experience frequent visitation from recreationists and biologists. In Sonora, however, they are seldom-visited wildlands. Because of their remoteness, a tendency for Mexican biologists to work more often in central and southern Mexico, and an arbitrary political boundary bisecting this amazing and diverse region, few biologists have ventured into the southern Sky Islands. Few people enter the highlands of the Mexican Sky Islands for any reason; even the *vaqueros* common in remote parts of lowland Sonora are seen only rarely in these mountains. The costs of constructing and maintaining infrastructure for cattle in this rugged, remote terrain are generally prohibitive for ranching, as they are for extracting most natural resources.

Elegant Trogon *(Trogon elegans)*.

Sky Jacobs

Sky Jacobs

Stephen Minter

Through the centuries, and even now, these more remote Sky Islands have largely been left alone, with one significant exception. Logging took a serious toll on wildlife and habitat between the 1930s and 1950s, when stands of old-growth pine forest were decimated in the larger ranges. More than a half-century later these forests are still recovering. Most pine forests are not yet mature enough to make logging cost-effective, and commercial logging is now rare. In the adjacent Sierra Madre, where pine forests are extensive and access is easier, large-scale logging continues, and little old-growth forest remains.

The full impact of commercial logging is unknown, but it likely had broad negative effects on a diverse range of wildlife. The imperial woodpecker, for example, once the largest woodpecker on Earth and endemic to the Sierra Madre Occidental (and likely the larger southern Sky Islands), has been declared extinct. Populations of thick-billed parrot, which were once abundant, have declined, with flocks now restricted to a limited number of localities in the higher parts of the Sierra Madre Occidental. However, it is difficult to say what effects logging had on the distribution and abundance of birds and other wildlife in the southern Sky Islands and nearby Sierra Madre, because baseline data from before the mid-twentieth century is sparse. Very few biologists had explored the Mexican Sky Islands before logging began.

In the 1950s, however, one biologist traveled to many places that few had seen. Ornithologist and explorer Joe Marshall, Jr., worked throughout the Sky Islands on both sides of the U.S.-Mexico border studying birds and their oak and pine-oak woodland habitats. In 1957 Marshall published *Birds of Pine-Oak Woodland in Southern Arizona and Adjacent Mexico,* a comprehensive and often poetic account of bird distribution, abundance, habitat use, and biogeography in the Madrean Sky Island Region and neighboring Sierra Madre Occidental. Marshall's work provided an important baseline on the distribution and abundance of birds in the region, including in 9 Sky Islands in Sonora. The late Peter Warshall, who authored *The Madrean Sky Island Archipelago: A Planetary Overview,* an insightful presentation on the biogeography of the Madrean Sky Islands said of Marshall's work, "Never surpassed, this elegant monograph described the stacking of biotic communities on each island mountain from the Mogollon Rim to the Sierra Madre."

Since 2000, Aaron Flesch and his associates have followed in Marshall's footsteps, visiting little-known landscapes of the Sky Islands in Mexico. Flesch's main goal since 2008 has been to describe the patterns of bird distributions across the region, but he and his field crews have also collected important data on other animal and plant groups. As a participant in several of his field expeditions, I can attest to the multiplicity of challenges that characterize field work in this remote, rugged, and fascinating region. We traversed untold miles of terrible roads, backpacked and mule-packed through remote and steep terrain, and braved thunderstorms, lighting, and other dangers. (Although often overblown in the media, these dangers do include regular encounters with illicit drug growers and smugglers.) Regardless, most people in the region are very friendly, helpful, and interested in wildlife, and local landowners deserve special recognition for generously granting access to their land and always lending a hand.

Above: Sierra El Tigre.
Left: Hermit thrush *(Catharus guttatus).*

Supported by the National Park Service and Desert Southwest Cooperative Ecosystem Studies Unit, as well as the Mexican Park Service (CONANP), Flesch and his associates have collected data in almost every Madrean Sky Island south of the U.S.-Mexico border since 2008. He has been very fortunate to have the help of young Mexican biologists, especially Carlos Gonzalez and Javier Amarillas. Thus far, they have surveyed birds and measured habitat in 26 Sky Islands in Sonora and 7 areas in the adjacent Sierra Madre, covering an area much broader than that visited by Marshall. Fieldwork for this project ended in 2012, and research reports are now in preparation. Many of Flesch's observations have been submitted to the publicly accessible MABA database at www.madrean.org.

Flesch has documented several new breeding bird species in the Sonoran Sky Islands, including short-tailed hawk, brown-backed solitaire, crescent-chested warbler, and slate-throated redstart, as well as other notable likely breeders such as the white-striped woodcreeper and flame-colored tanager. He has also observed northern species at the extreme southern end of their ranges, such as the first breeding western tanagers and hermit thrushes in mainland Mexico. Beyond these notable records, extensive distance sampling at over 1,500 points has enabled him to estimate the densities of more than 60 species of breeding birds in each Sky Island he has surveyed.

Due to the limited fieldwork carried out in the southern Sky Islands, observations of even common plants and ani-

Above: Sierra Azul.
Right: Rufous-capped warbler *(Basileuterus rufifrons).*

Sky Jacobs

Stephen Minter

Sky Jacobs

Sky Jacobs

mals are often noteworthy. Thus, when possible, Flesch has photographed and cataloged mammals, herpetofauna, and plants, which has resulted in many observations of species outside their previously known ranges. Flesch has collected the first Sonoran records of species such as *Rhamnus californica, R. ilicifolia* (coffeeberry and hollyleaf redberry, respectively—both buckthorns), and *Dalea tentaculoides* (Gentry's indigobush). Other notable observations include the northernmost observation and only the second record for the Sky Islands of *Pinus yecorensis* (Yecora pine), near Nacozari de Garcia; the northernmost and first Sky Island record for *Quercus durifolia (roble prieto*/dark oak), in the Sierra el Tigre; and the westernmost observation and first Sky Island record of *Ilex rubra* (a holly), in the Sierra Opusera. Flesch has also documented many formerly unrecorded populations of species that are common in the northern Sky Islands but rare in the south; examples include *Populus tremuloides* (quaking aspen) and *Quercus gambelii* (Gambel oak).

Flesch's fieldwork is making a landmark contribution to our understanding of the natural history and diversity of the region. In addition, this and other field projects are bringing researchers, institutions, land managers, and landowners closer together. Documenting the biodiversity of the Sky Island Region, including that of the many ranges south of the border, will help us better understand and therefore better protect the species that live here for the benefit of future generations. S

SUGGESTED READING

Flesch, A. D., and L. A. Hahn. 2005. "Distribution of Birds and Plants at the Western and Southern Edges of the Madrean Sky Islands in Sonora, Mexico." In *Connecting Mountain Islands and Desert Seas: Biodiversity and Management of the Madrean Archipelago II.* Proc. RMRS-P-36 Fort Collins, CO. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Warshall, P. 1995. "The Madrean Sky Island Archipelago: A Planetary Overview." In *Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico.* General Technical Report RM-GTR-264. U.S. Forest Service. Tucson, AZ.

Above: Dew on leaves, Sierra Huachinera.
Below: Sharp-shinned hawk chicks *(Accipiter striatus)*, Sierra el Tigre.

Michele Lanan

Winter Ants *(Prenolepis imparis)* tending aphids.

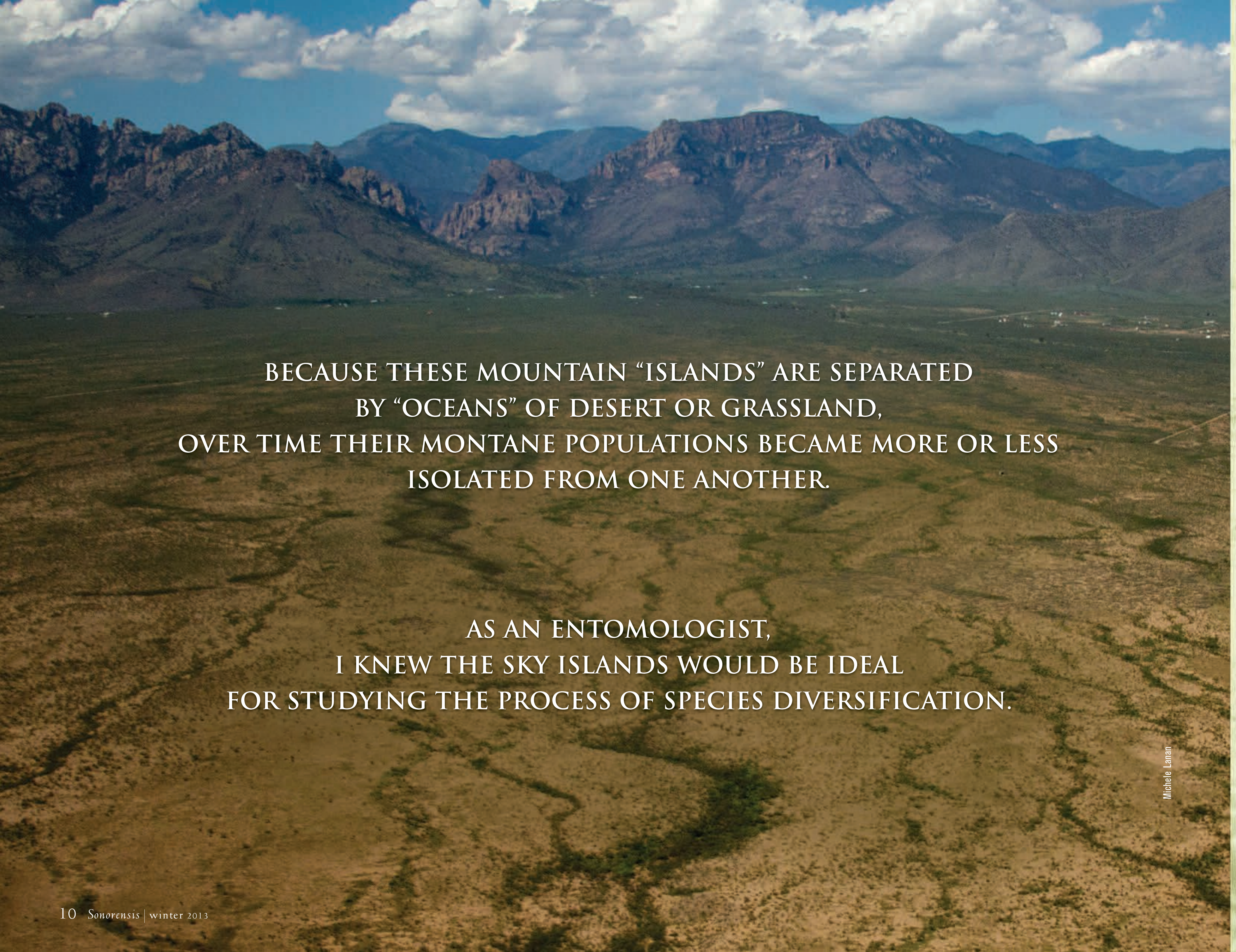
Wendy Moore, Ph.D.
Assistant Professor and
Curator of the University of Arizona Insect Collection,
Department of Entomology,
University of Arizona

ASAP: THE ARIZONA SKY ISLAND ARTHROPOD PROJECT

SKY ISLANDS AND TERRESTRIAL ARTHROPODS

Southeastern Arizona's Sky Islands have long fascinated naturalists because of the extraordinary biological diversity and the complex geographical distributions of species found in these ranges. Because these mountain "islands" are separated by "oceans" of desert or grassland, over time their montane populations became more or less isolated from one another. Take a beetle that lives only in the highest biome (Mixed Conifer Forest) on Mount Lemmon; its closest relatives live in the Mixed Conifer Forest of other Sky Islands, such as the Pinaleños and Chiricahuas. Since these montane populations are restricted to different mountaintops and separated from one another by desert seas, they often evolve and adapt independently, eventually becoming distinct enough to warrant separate species or subspecies status (a process biologists call "species diversification"). And, because arthropods (insects, isopods, millipedes, mites, spiders, scorpions, etc.) reproduce frequently and in larger numbers, they can evolve into distinct populations at a faster pace than most larger animals. As an entomologist, I knew the Sky Islands would be ideal for studying the process of species diversification.

Ecologically, arthropods are critical. They drive key ecosystem processes, such as pollination, litter decomposition, nutrient recycling, and soil aeration, and are essential food for reptiles, birds, and small mammals. However, their life histories, popu-



BECAUSE THESE MOUNTAIN "ISLANDS" ARE SEPARATED
BY "OCEANS" OF DESERT OR GRASSLAND,
OVER TIME THEIR MONTANE POPULATIONS BECAME MORE OR LESS
ISOLATED FROM ONE ANOTHER.

AS AN ENTOMOLOGIST,
I KNEW THE SKY ISLANDS WOULD BE IDEAL
FOR STUDYING THE PROCESS OF SPECIES DIVERSIFICATION.

Michele Lanan

lation dynamics, survival strategies, value to society, and conservation status are still relatively poorly known. The enormous potential for researching the natural history of arthropods in the unique natural laboratories of the Sky Islands led to the founding of the Arizona Sky Island Arthropod Project (or ASAP), in my lab in the University of Arizona's Department of Entomology.

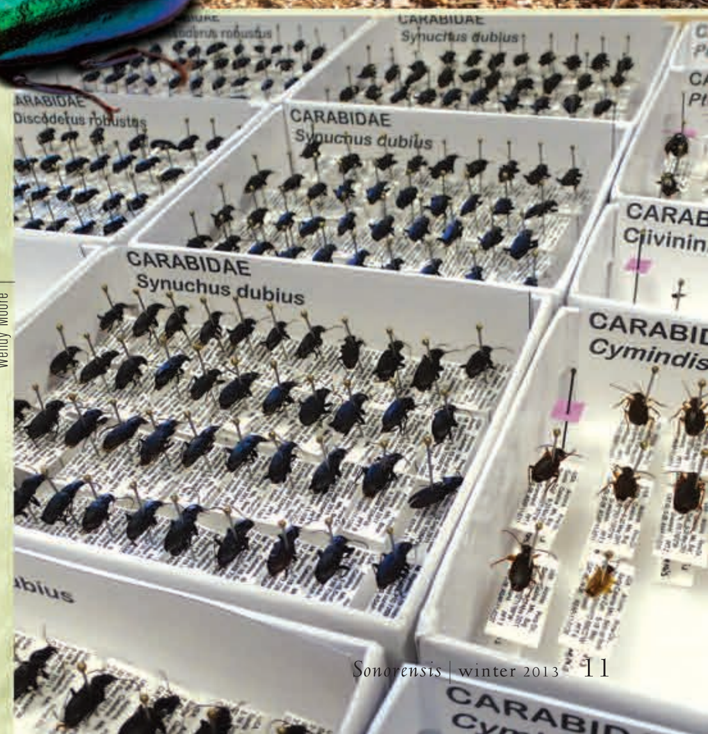
The ASAP project has undertaken the ambitious job of documenting the arthropod fauna, not just of the nearby Santa Catalina Mountains, but of all the Sky Islands in southeastern Arizona. The panorama of isolated vegetation types throughout this region provides us with perfect natural replications of habitat for ecological studies. Using these natural laboratories, we are investigating how arthropod communities have assembled within the Sky Island biomes and diversified among the isolated ranges. The fundamental questions we are addressing include:

- *Which arthropods inhabit Arizona's Sky Islands, and how are these species distributed within the region?*
- *What are the biogeographic affiliations of the Sky Island arthropods?*
- *What are the evolutionary relationships of the Sky Island arthropods? Which groups have radiated within the Sky Island Region?*
- *What are the over-arching drivers that structure arthropod communities in the Sky Islands (e.g. moisture, temperature, soil type, plant associations)?*
- *How might montane arthropod communities respond to rapidly changing climate conditions?*

We began our research on the ground in the Santa Catalinas—one of only three ranges north of the U.S.-Mexico border with the full sequence of biological communities found in the Sky Island Region—from desertscrub to subalpine fir forest [see diagram of biomes, page 17]. In early 2011, ASAP researchers established 66 sampling sites for arthropod collection along the elevation gradients of the range—along the Mt. Lemmon Highway on the south side of the Catalinas, and along the Control Road on the north side. In 2011 and 2012, the ASAP team deployed pitfall traps at each site for two weeks in May (pre-monsoon) and again for two weeks in September (post-monsoon), capturing the ground-dwelling arthropods that were active during those periods.Preserved specimens were brought to the lab to be sorted and identified by members of the ASAP team. Data on the number of specimens of each species collected by each trap are being carefully recorded, and the specimens themselves are being deposited in the University of Arizona Insect Collection.

Wendy Moore

Alex Wild



Wendy Moore

Far left: Chiricahuas rising from the desert floor.
Upper right: Pitfall trap.
Cut out: Bark-gnawing beetle *(Temnoschelia chloradia)*. These brilliant metallic green beetles can be found on and under the bark of many types of trees, where they feed on larvae of various bark-boring insects.
Lower right: Carabid beetle collection.

Above left: Beyer's scarab *(Chrysina beyeri)*, one of three jewel scarab species found in Arizona. Taken in Madera Canyon, Santa Ritas. Middle: Purple pleasing fungus beetle *(Gibbifer californicus)*, upper left in photo, and larvae. Right: Big-headed ants *(Pheidole rhea)* found in Molina Basin, Santa Catalinas.


Above left: Santa Ritas. Right: Field work in desert grassland habitat on Mt. Lemmon. Cut out right: Snail-eating bettle *(Scaphinotus petersi)*. This attractive ground beetle has evolved specialized elongate mouthparts for attacking snails in their shells. Whereas adults are specialized for eating snails, the larvae are predatory generalists, feeding on various small insects.

Although all arthropod groups are under study, ASAP has concentrated so far on two super-diverse groups: beetles (Coleoptera) and ants (Hymenoptera, family Formicidae). Ants are possibly the numerically dominant family of insects on Earth, representing 10–15 percent of the entire animal biomass in terrestrial ecosystems. To date, nearly 100 ant species have been identified in the Santa Catalinas (with more samples remaining to be worked up). The most common are acrobat ants (*Crematogaster* spp.), highway ants (*Forelius* spp.), little black ants (*Monomorium* spp.), and big-headed ants (*Pheidole* spp.), while the most scarce, to date, are small, cryptic species whose colonies are smaller than those of most other ants (e.g. *Hypoponera* spp., *Stenamma* spp.).

Beetles comprise the most diverse group of organisms, with approximately 370,000 described species worldwide. Some beetle species are top arthropod predators, while other species feed on plants, decaying organic matter, or fungus, and thus play important ecological roles in almost every terrestrial habitat. To date, 197 species of ground-dwelling beetles have been collected and identified in ASAP's surveys in the Catalinas. Initial analyses reveal a species distribution pattern in which species with temperate (northern) ancestral distributions are generally found at higher elevations, while Neotropical (southern) species are generally found at lower elevations on the mountains. Among the largest and most noticeable are ground beetles (family Carabidae), darkling beetles (family Tenebrionidae), pleasing fungus beetles (family Erotylidae), longhorn beetles (family Cerambycidae), and scarab beetles (family Scarabaeidae).

BEYOND ARTHROPODS

In 1963, ecologists Robert Whittaker and William Niering systematically surveyed the plants along the Mt. Lemmon Highway, from desertscrub to subalpine fir forest.In the ASAP project, we also surveyed plants at each of our 66 study sites in the Catalinas, including the same 20-mile stretch surveyed by Whittaker and Neiring. Comparing the elevations of the 27 most common plant species in our survey with their historic data, we found that almost every species has shifted its lower elevational boundary significantly upslope; in eight species, lower elevation limits have increased by more than 800 feet, and some as much as 1000 feet, including alligator juniper (*Juniperus deppeana* var. *deppeana*), New Mexico groundsel (*Packera neomexicana*), and meadow rue (*Thalictrum fendleri*). The best hypothesis to explain these upward shifts is that an increasingly warmer climate and the ongoing persistent drought in southern Arizona are driving species up the mountain, as predicted by climate models for the Southwest (see Climate Change and the Sky Islands, this issue). Here in Tucson, temperatures have increased at a mean rate of 0.25°C *per decade* since 1949. In the Catalinas, as in all the Sky Islands, other effects of warming climate and prolonged drought are already evident (e.g., increased fire, pest outbreaks, spread of invasive species, etc.), and plant communities are under stress. Additional temperature increases of as little as a few degrees could push Sky Island plant and arthropod species to even higher elevations, potentially causing local extinctions of endemic species and subspecies and other evolutionarily unique lineages.

ASAP ONWARD

This past summer ASAP began collections in the Pinaleños, Huachucas, and Chiricahuas. In the coming years we will sample many other ranges, and we expect to be collecting data in the Sky Islands for another 30 years. As the ASAP project grows, new patterns in the deep history of the montane arthropods of our region will emerge, models predicting how these animals will respond to changing climates will be developed, and threatened species and populations will be identified. Information from ASAP will contribute to science-informed public policy in environmental conservation, as well as deepen our understanding of the small animals that help make this region so diverse.

ASAP COLLABORATORS:

Sandra Brantley, University of New Mexico;
Rick Brusca, Arizona-Sonora Desert Museum (ASDM)/University of Arizona (UA);
Jeff Eble, UA,; Kim Franklin, ASDM;
Antonio Gomez, UA; Gene Hall, UA;
Jeff Henkel, UA; Garrett Hughes, UA;
Paul Marek, UA (now at Virginia Tech);
Reilly McManus, UA;
Marty Meyer, UA (now at Pomona College);
John Palting, UA; Jason Schaller, UA;
John Wiens, ASDM; Alan Yanahan, UA. S

SUGGESTED READING

NEW

Brusca, Richard C., and Wendy Moore. 2013. *A Natural History of the Santa Catalina Mountains, Arizona, with an Introduction to the Madrean Sky Islands.* ASDM Press: Tucson, AZ.

Brusca, R. C., J. F. Wiens, W. M. Meyer, J. Eble, K. Franklin, J. T. Overpeck, and W. Moore. 2013. "Dramatic Response to Climate Change in the Southwest: Robert Whittaker's 1963 Arizona Mountain Plant Transect Revisited." *Ecology & Evolution* 3:3307-3319.

Moore, W., W. M. Meyer, J. A. Eble, K. Frankliln, J. F. Wiens, and R. C. Brusca. 2013. "Introduction to the Arizona Sky Island Arthropod Project (ASAP): Systemics, Biogeography, Ecology, and Population Genetics of Arthropods of the Madrean Sky Islands." In *Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelego III.* Proceedings RMRS-P-67, U.S. Forest Service, Rocky Mountain Research Station.

Above: Alpine wood sorrel flower *(Oxalis alpina).*

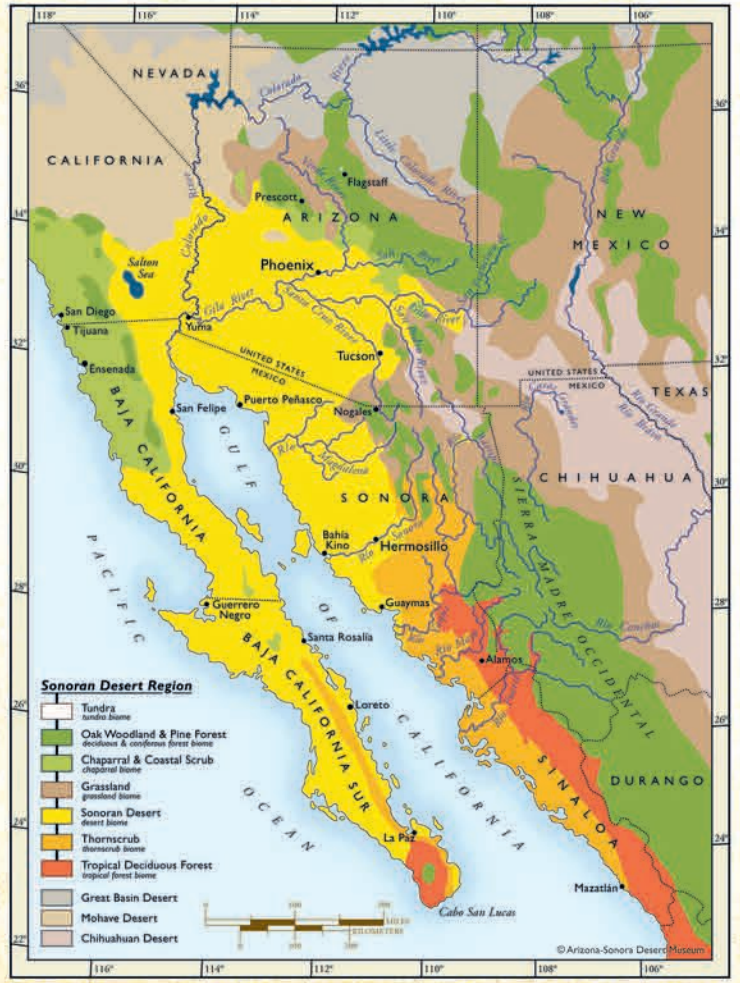
Mapping evolutionary pathways: SKY ISLANDS AS A NATURAL LABORATORY

Lluvia Flores-Rentería, Ph.D.,
Postdoctoral Researcher, Biological Sciences, Northern Arizona University
Fernanda Baena-Díaz, Ph.D.,
Instituto de Ecología, Universidad Nacional Autónoma de México
Jessica Pérez-Alquicira, Ph.D.,
Postdoctoral Researcher, Ohio Agricultural Research and Development Center, Ohio State University
Francisco Molina-Freaner, Ph.D.,
Ecología de la Biodiversidad, Instituto de Ecología, Universidad Nacional Autónoma de México
César A. Domínguez, Ph.D.,
Ecología Evolutiva, Instituto de Ecología, Universidad Nacional Autónoma de México

For us, the Sky Islands are a constant source of wonder and amazement; sometimes, we feel like we are walking in the clouds. And the more we know about the wealth of biodiversity here, the more we are amazed. Over the last twelve years at the Instituto de Ecología of the Universidad Nacional Autónoma de México, we have been studying two distinct species that live in the Madrean Sky Islands of the southwestern United States and northern Mexico. These isolated mountain ranges rising from an arid sea make up a "stepping stone archipelago" between two long and wide chains of mountains—the Rocky Mountains and the Sierra Madre Occidental. In the great low-elevation gap between them, on mountains with woodlands or forests, species from both the southern and the northern ranges grow together.

If you explore a Madrean Sky Island, you will notice a gradual change in vegetation as elevation increases (see figure, pg 17), from desertscrub at the lowest elevations through desert grasslands, oak grasslands, oak woodlands and chaparral, and, in the taller ranges, pine-oak woodlands and pine forests dominated by Arizona and ponderosa pines, and, eventually, mixed conifer forests with pine, fir, and spruce. Although some species show little genetic variation between mountain ranges, other species have evolved and radiated on these "islands," which serve as natural laboratories for the study of evolution because conditions differ from island to island (as in the case of Darwin's finches in the Galapagos).

Our team is exploring the tremendous variation in plant reproduction systems across different mountain populations of the same species. To this end, we have been studying two species in the Sky Islands: alpine wood sorrel *(Oxalis alpina)*, a small herbaceous angiosperm (or flowering plant) pollinated by insects, and border pinyon pine *(Pinus discolor)*, a gymnosperm (or cone-bearing plant) pollinated by wind.



Sonoran Desert Region Map

THE RESEARCH: ALPINE WOOD SORREL

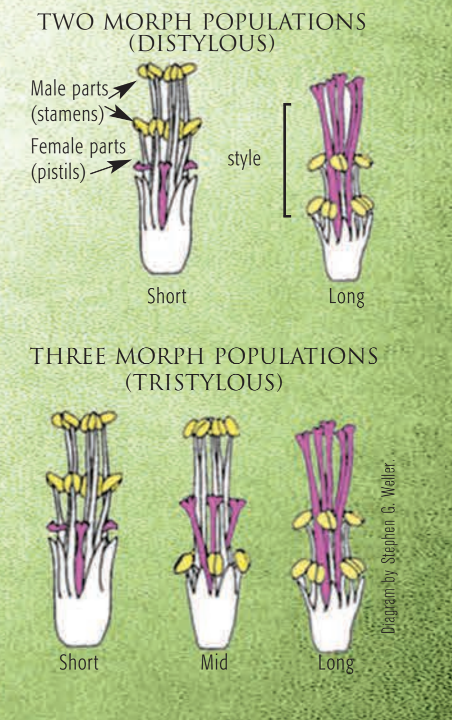
Oxalis alpina uses one of the most complex and rare reproductive systems in the plant kingdom. Within a single population you may find two or three different flower types. In populations with two flower types, some plants have long styles (female parts) that rise above the shorter stamens (male parts), while other plants have flowers with short styles and long stamens. A population consisting of two different flower types is called distylous. Other populations are tristylous, having flowers with long or short styles, as described above, as well as flowers with styles of intermediate length between two sets of stamens.

In order to understand why some populations are distylous and others tristylous, we first asked if ecological conditions differed on the mountains with these populations. One important driver of change in plants is their relationship with pollinators, and we suspected that each Sky Island might have a different suite of pollinator species, which could be responsible for the variation in floral types. Surprisingly, we did not find differences in the pollinators among populations of *O. alpina.* The common pollinators are two small bees in the genus *Heterosarus,* neither of which displays a preference for one flower type over another, suggesting that pollinators are not the cause of the variation in the reproductive system of this species.

Still looking for an answer, we turned to a second approach using genetic markers (DNA sequences) to reconstruct the history of these populations. We found that populations of *O. alpina* in northern ranges have less genetic diversity than southern populations and a lower frequency of flowers with mid-length styles. This suggests that since the last glaciation, *O. alpina* has migrated to northern Sky Island ranges, and that random colonization events may partially explain the reduction in the frequency of flowers with mid-length styles.

Further investigation revealed that another reason for the shift to distyly relates to the loss of what is known as a "heteromorphic incompatibility system" in *O. alpina.* This system prevents fertilization between individuals of the same floral type and allows fertilization to occur *only* when pollen from stamens of a certain length reaches styles of the same length. This means that crosses are only possible between individuals of different floral types. This system results in populations with roughly equal proportions of the three flower types. However, we found that in northern populations of *O. alpina,* flowers with long and short styles have lost this incompatibility system as a result of a genetic mutation. Therefore short- and long-styled flowers are able to cross-pollinate, while flowers with mid-length styles are not. With the loss of the incompatibility system, flowers with short and long styles could fertilize each other more, thus outcompeting flowers with mid-length styles, which would explain

Above: Border pinyon pollen cones *(Pinus discolor).*



Frank Rose

Frank Rose

Above top: Alpine wood sorrel *(Oxalis alpina)*. Above: Border pinyon pine tree *(Pinus discolor)*.

the shift of northern populations towards distyly. Thus, we propose that natural selection in combination with the recent northern migrations is responsible for the emergence of distyly in *O. alpina*.

THE RESEARCH: BORDER PINYON PINE

As we have noted, many species became divided into spatially isolated populations as a result of the last glaciation. Some of these isolated populations, like those of *O. alpina*, have indeed followed independent evolutionary paths because they no longer exchange genes with other populations due to the limited distance their pollen is able to travel.

In other species, however, this spatial isolation has not led to genetic isolation. One example is the border pinyon pine *(Pinus discolor)*, the seeds of which, known as pine nuts or pinyon nuts, are savored by animals and people alike. *Pinus discolor* diverged from *P. johannis* (Johann's pine) a couple of million years ago. Today *P. johannis* is found in the Sierra Madre Oriental, and *P. discolor* in the Sierra Madre Occidental. Since the end of the Pleistocene (approximately 10,000 years ago) *P. discolor* has retreated from lower elevations, where we find Sonoran desertscrub today, upslope into the Sky Islands.

Pinus discolor is pollinated by wind. The movement of its pollen is facilitated by two air sacs, which make the pollen grains look a little like Mickey Mouse. Wind can carry this pollen to mountains more than 100 miles away, thus maintaining a genetic connection between physically separated populations. We have found evidence of this connectivity by analyzing genetic markers for *Pinus discolor.* Even remote populations of *P. discolor* are genetically similar, and from this we can surmise that the species has changed little since becoming confined to isolated Sky Island habitats 10,000 to 12,000 years ago.

Wind pollination is one explanation for close genetic connections across the Sky Islands, but it is not the only way genes can be dispersed. Seeds also play an important role in dispersal; however, as pine nuts are heavy and wingless, they depend on small mammals and birds, particularly jays, for dispersal. Pinyon jays may travel over 20 kilometers (but typically less than 5 kilometers) to cache pinyon nuts, and small mammals disperse seeds even shorter distances. Therefore we do not think that animals often move border pinyon pine seeds between mountain ranges.

By combining both ecological and genetic approaches, we have been able to unravel the evolutionary histories of two distinct species with different reproductive systems and pollination types in the Sky Islands. Each Sky Island species offers us a glimpse into the past and an opportunity to better understand the ecological and evolutionary processes that shape the world we live in. Moreover, understanding how the changing environment of the past has led to the patterns we see today will guide us in our efforts to manage species in the face of the rapidly changing environment of the future. S

SUGGESTED READING

Rose, Frank S. 2012. *Mountain Trees of Southern Arizona: A Field Guide.* ASDM Press, Tucson, AZ.

Rose, Frank S. 2011. *Mountain Wildflowers of Southern Arizona: A Field Guide to the Santa Catalina Mountains and Other Nearby Ranges.* ASDM Press, Tucson, AZ.

BIOME "STACKING"

is an important and characteristic feature of the Madrean Sky Islands. On the highest Sky Islands in Arizona (such as the Santa Catalinas, Pinaleños, and Chiricahuas), up to eight biomes can be recognized, as shown in this schematic. Although the figure shows clear boundaries of these biomes for illustrative purposes, in reality they are not sharply delineated, and transition zones are common. Elevation is an overriding factor, but the position at which a biome occurs is also strongly regulated by aspect—the direction a mountain slope is facing. Southern and western slopes receive more sunlight and are warmer and dryer, shifting biomes upslope; whereas northern and eastern exposures receive less sunlight and are cooler and moister, shifting biomes downslope. In addition, the elevation of each biome in a mountain range is influenced by the latitude at which the mountains occur.

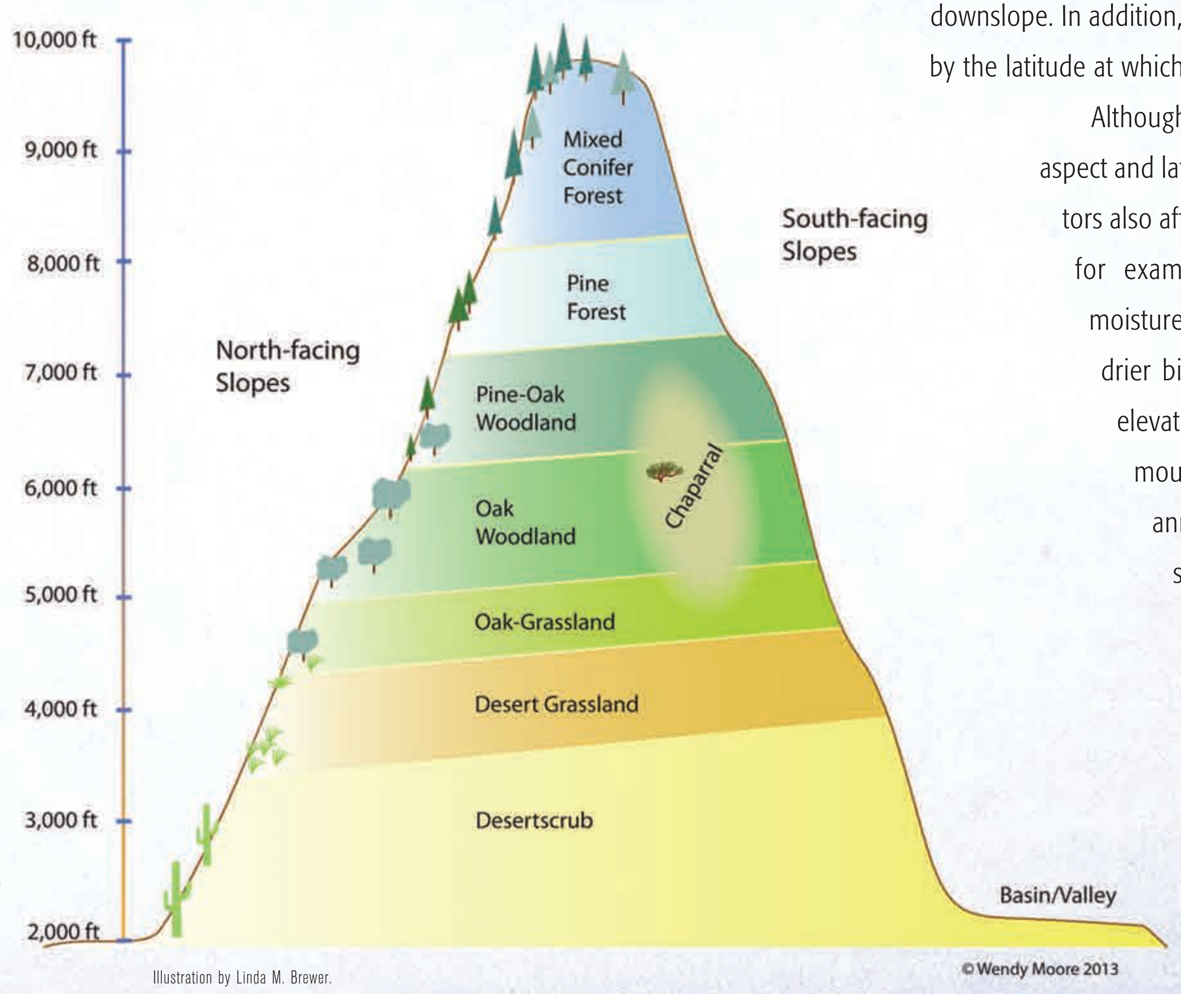


Illustration by Linda M. Brewer.

Although the main determinants of plant community type are elevation, aspect and latitude, slope angle, soil type, drainage, exposure, and other factors also affect what plants will be found at any given site. Limestone soils, for example, are highly permeable to water and do not retain moisture well, thus creating conditions that favor plants from lower, drier biomes (e.g., desert plants often appear on limestone soils at elevations where grasslands would normally occur). Also, because mountains of lower elevation and smaller overall size receive less annual precipitation than do higher mountains, their biomes are shifted higher in elevation. Although Chaparral is an important and well-developed plant community in California and Baja California, in the Madrean Sky Islands it is relatively low in species diversity and occurs only in patches where the climate is notably dry (e.g., exposed southwestern slopes, ridge tops, etc.).

The University of Arizona
JAGUAR SURVEY PROJECT

Melanie Culver, Ph.D.,
School of Natural Resources and the Environment, University of Arizona
Lisa Haynes, Ph.D.,
Wild Cat Research and Conservation Center,
School of Natural Resources and the Environment, University of Arizona
Kirk Emerson, Ph.D.,
School of Government and Public Policy, University of Arizona

Above: Jaguar *(Panthera onca)*, photo taken with Sky Island Alliance night cameras. Right: A jaguar in the Bootheel area of Southwestern New Mexico in 2006.

The jaguar, the largest cat in the Western Hemisphere, is historically native to the southwestern United States as well as to the more tropical areas of Mexico and Central and South America. In Arizona, rare sightings were reported through most of the twentieth century, but in the later decades breeding populations seemed to have disappeared. Jaguars as resident wildlife north of the border had been dismissed from the public mind and the minds of most of the conservation community. Then, in 1996, two adult male jaguars were photographed in separate circumstances in Sky Islands in southwestern New Mexico and southeastern Arizona. That news made a splash. Since then, several more of the big spotted cats, all of them males, have been sighted in the borderlands of both states. The probable source of these wandering males is a breeding population in the wild, rugged, and remote Sierra Madre Mountains of Sonora, Mexico, approximately 120 miles south of Douglas, Arizona. This Sierra Madre jaguar population thrives in an area of relatively continuous and unfragmented habitat, including a mix of ranchlands and protected reserves. It is the northernmost known breeding population of jaguars.

In most species of wild cats worldwide, young males tend to leave areas where they were raised and travel long distances before establishing their own home ranges. This is the most likely scenario for explaining the sporadic occurrence of jaguars in Arizona and New Mexico over the last couple of decades. One hundred years ago, jaguars had a much broader distribution in the United States, but the historic population is now reduced to a few individuals that inhabit secluded areas away from intense human disturbance in Sky Island ranges and adjacent landscapes.

Very little is known about what jaguars are doing in this northernmost edge of their distribution—how many are here, how long they stay, what they prey upon, and how often they roam in which landscapes. Addressing this lack of knowledge, the University of Arizona has embarked on a multi-year project to detect and monitor jaguars along the northern side of the U.S.-Mexico border south of Interstate 10, from the Baboquivari Mountains in Arizona, west to the "boot-heel" region of New Mexico. The project hopes to generate scientific information that can help answer important conservation and ecological questions about jaguars in Arizona and New Mexico. With funds provided by the U.S. Department of Homeland Security, the project will establish and implement a completely non-invasive survey and monitoring program for jaguars, ocelots, and other wildlife. Our goals are, first, to identify individual jaguars on the landscape by their unique spot configurations in photographs and unique scat/hair DNA profiles, and, second, to obtain information on the ecological relationships of jaguars to their habitat, prey, and human impacts on the landscape. In spite of the confined distribution of jaguars currently documented north of the border, this survey and monitoring is taking place on 16 different mountain ranges in Arizona and New Mexico.

No animals will be captured or radio-collared in this study. The main tools we use to detect and monitor jaguars are motion-sensor "trail" cameras, placed in remote areas where jaguars are most likely to be found. We also collect large carnivore scat for genetic analyses. At times, we collect scat with the assistance of a scat-detection dog—a Belgian Malinois named "Mayke." Mayke has had intensive training in searching out and detecting the scent of jaguar scat with the assistance of her handler, and the use of the dog in the field increases our probability of finding jaguar scat. DNA analyses of the

Above: Ocelot *(Leopardus pardalis)*. Middle: Jaguar *(Panthera onca)*, photo taken with Sky Island Alliance night cameras. Right: Mayke and his handler, Chris Bugbee.

scats not only provide a way to identify the number of jaguars on the landscape, they also allow us to determine the amount of genetic variation among those individuals. In general, we are hoping to find high levels of genetic variation, knowing full well that small isolated groups of individuals often have reduced levels of genetic variation—a sign of less than optimal population size.

Using analytical software, the University of Arizona team will scrutinize all wildlife photographs captured by our trail cameras, not just those of the spotted cats, which will generate one of the most comprehensive analyses of wildlife throughout this border region to date. Our methods may also detect ocelots *(Felis pardalis)*, a species for which there are few scientific data regarding presence in Arizona.

Jaguar research and conservation is only possible with the active support of the people who live and work on the land. Accordingly, the survey team is proactive in communicating with the ranching community across the study area. From the outset, we have been working closely with local ranchers, public agencies, wildlife scientists, and other stakeholders to ensure timely coordination and communication to facilitate this ambitious and much-needed scientific research.

The jaguar project is one of many studies being conducted around the world by the University of Arizona's Wild Cat Research and Conservation Center (www.uawildcatresearch.org). The Wild Cat Center is dedicated to studying and conserving the 36 species of wild cats worldwide and currently has projects in India (tigers), Namibia (caracal cats), Chile (Andean mountain cats), and Zambia (African lions and cheetahs), as well as studies focusing on the mountain lion *(Puma concolor)* and bobcat *(Lynx rufus)* here in the Sonoran Desert. What better place for a global Wild Cat Center than the home of the University of Arizona… Wildcats! S

SUGGESTED READING

Brown, D. E., and C. A. López-Gonzáles. 2001. *Borderland Jaguars: Tigres de la Frontera.* University of Utah Press, Salt Lake City, UT.

Rizzo, W. *"Return of the Jaguar?" Smithsonian Magazine,* December 2005.

Climate Change and the SKY ISLANDS

Jonathan Overpeck, Ph.D.
Professor, Departments of Geosciences and Atmospheric Sciences,
University of Arizona

Snow on saguaros in the mountains.

The Sky Islands, and their broader U.S.-Mexico border region, are facing one of the most daunting climate change challenges in North America. Climate scientists now have a high level of confidence that global climate change is occurring and that most of this change is driven by humans. But, as with many things, it is the regional manifestation of global trends that matters most to ecosystems, resource managers, and conservationists. The Sky Islands are a case study in how climate change will matter.

There is already unusual clarity in what lies ahead for the climate of the Sky Island Region. Like most regions of the globe, southwestern North America has already been warming steadily and noticeably. Without exception, climate models indicate that the region should be warming, and that's exactly what we see. Climate models are in agreement with thermometer measurements, and this agreement gives us confidence in the model projections for the future—that is, continued warming.

Observations also indicate that far more hot temperature records are being broken than cold, again in line with model projections. Thus, there is good reason to plan for an ever-increasing severity of hot temperature extremes into the future. Longer periods of excessive heat, hotter days and nights, as well as less frequent cold conditions are all a sure bet.

Interestingly, the latest climate science indicates that we should continue to see cold air outbreaks in winter, and still have some record low temperatures at times. But the Sky Islands of the future are almost all about hot and hotter.

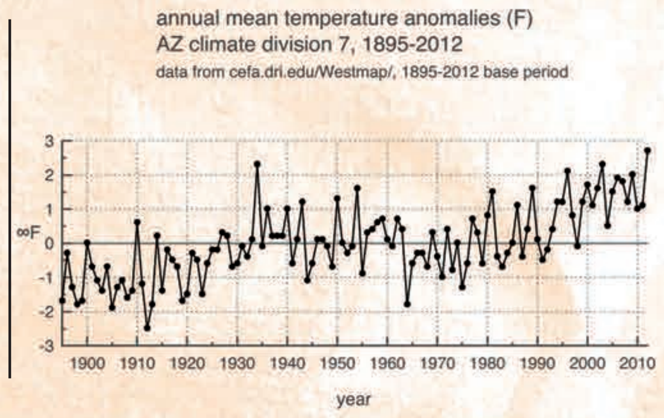
FOREST IMPACTS AND SNOW

The impacts of increasing temperatures appear to be especially challenging for the forests of the Southwest. Higher temperatures mean that more moisture in trees will be lost to the atmosphere; thus, increasingly drought-stressed trees will be less able

Above left: White Water Draw under an overcast sky, rain in the distance. Middle: Santa Ritas. Right: Desert lightning.

Above left: Beetle infested pines in the Chiricahua Mountains.

The climate of the Sky Islands region has warmed in recent decades. For the area encompassing Pima, Santa Cruz, Cochise, Graham, and Greenlee counties in Arizona, annual mean temperature anomalies – the difference between the average temperature of a given year and that of all years over a longer time period – lately have been about +1°F to +2°F higher than the average annual temperature calculated from 1895 to 2012. Jeremy Weiss, University of Arizona, made this figure with temperature data from the Western Climate Mapping Initiative (cefa.dri.edu/Westmap/).



to deal with other threats such as fungal pathogens and insect pests. This ripple effect appears to have already caused substantial tree death in the Southwest and beyond, and could become a major threat to the forests of the Sky Islands (see ASAP: the Arizona Sky Island Project, this issue).

With high confidence in warming comes high confidence in other key aspects of climate change. Snow is an important natural reservoir of soil moisture and streamflow in the Sky Islands, but this hydrological buffer during the late spring and early summer dry period will become more and more rare in the future. Hotter temperatures mean that more precipitation will fall as rain, and that snow that does fall will melt faster and sublimate more (a process by which frozen snow directly becomes water vapor in the air rather than first melting). Warmer temperatures will also cause any liquid snowmelt to be more susceptible to evaporation, or to being soaked up by soils that have dried out prematurely because of higher temperatures and evaporation. Lastly, warmer temperatures will increase the length of the growing season, translating into greater demand for soil moisture from vegetation. All of these impacts of observed warming mean less and less water to keep soils moist, streams and rivers flowing, and aquifers recharging. These will be challenging trends for the forests and other habitats of the Sky Islands, not to mention our human communities.

RAINFALL TRENDS

What are the chances that the Sky Islands will receive more rain and snow in the future to compensate for the impacts of warming? The short answer is familiar: not good. Although observations of precipitation are mixed in terms of whether projected declines in precipitation are already starting to occur, climate models indicate that mid-latitude storm tracks will move, on average, more and more poleward in both hemispheres. This will increasingly translate to less and less cool season rain and snow for the Sky Islands.

The Sky Islands only get about half of their precipitation in the cooler months, so it is important to also consider what will happen in the summer, especially with our monsoon. Here, the short message is that we don't really know. There is no clear century-long trend in the average amount of monsoon rainfall. That said, there are signs that the monsoon is getting more variable from year to year, and the latest generation of climate models suggests total monsoon rainfall won't change much, but that the monsoon season will start and end later in the season. For those who know the Southwest, this raises concerns about two things that we'd rather not see in the future. First, the hottest, driest time of the summer, the pre-monsoon "foresummer," could lengthen just as it is becoming rapidly hotter. And second, by shifting the monsoon further into the fall, it could increase the odds that monsoon moisture will get tied up with remnant tropical storms and their energy and excess water; this could mean more flooding rains. And we already know that rainfall isn't as beneficial, or even good, if it falls too fast and causes big runoff events and floods.

The summer, and increasingly the late summer and early fall, will likely become more flood prone for an additional reason. Climate scientists often assert that climate change will strengthen the "hydrological cycle" of the atmosphere because the warmer atmosphere will be able to hold more and more water vapor. This was predicted long ago, and it is now clearly happening. What it means for most places, including the Sky Islands, is that in the future when conditions are right for rain, it will tend to rain harder. This means more rain per minute, rather than more rain per storm.

THE SKY ISLANDS: CLIMATE CHANGE HOTSPOT

The other side of the hydrologic cycle is the dry side. Just as future rains will tend to be more intense, the increased moisture-holding capacity of the atmosphere is also apt to bring more time between rainfall events, more dry days, and more drought. A new analysis indicates that our climate models underestimate the risk of future drought—both decade-length drought like the current drought in the Sky Island Region, as well as multi-decade drought of the type seen in millennia-length tree-ring records. It also appears that there is a significant risk of both types of drought in the next 50 years, and that the risk would only be made worse by continued warming.

It is no surprise that the region encompassing the Sky Islands has been singled out as potentially the most persistent climate change hotspot in the United States, an assertion that only seems to grow stronger as we learn more. This is bad news, but there is also good news: the climate change signal in the Sky Island Region is so clear that we can begin well-informed adaptive planning now. Moreover, given this early warning, we have more time to determine how much climate change the natural and human systems of the Sky Islands can adapt to. This knowledge can, in turn, make clear the local consequences of climate change, as well as the levels of greenhouse gas pollution that are dangerous for the people and nature of the Sky Islands. As the concentrations of carbon dioxide in the atmosphere accelerate past the 400ppmv level (parts per million by volume), climate change impacts on the Sky Islands are very much becoming reality. S

SUPPORTING LITERATURE

Allen, C. D., A. K. Macalady, H. Chenchouni,et al. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management*, Vol. 259(4).

Ault T. R., J. E. Cole, J. T. Overpeck, et al. "The Continuum of Drought Variability in Western North America: Insights from Instrumental, Paleoclimate and Global Climate Model Data." In Press, *Journal of Climate.*

Breshears, D. D., N. S. Cobb, P. M. Rich, et al. 2005. "Regional Vegetation Die-off in Response to Global-change-type Drought." *Proceedings of the National Academy USA,* Vol. 102(42).

Cook, B. I., and R. Seager. 2013. "The Response of the North American Monsoon to Increased Greenhouse Gas Forcing. *Journal of Climate*, Vol. 118(4).

Diffenbaugh, N. S., F. Giorgi, and J. S. Pal. 2008. "Climate Change Hotspots in the United States." *Geophysical Research Letters*, Vol. 35.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* A report by the Southwest Climate Alliance. Island Press, Washington, D.C.

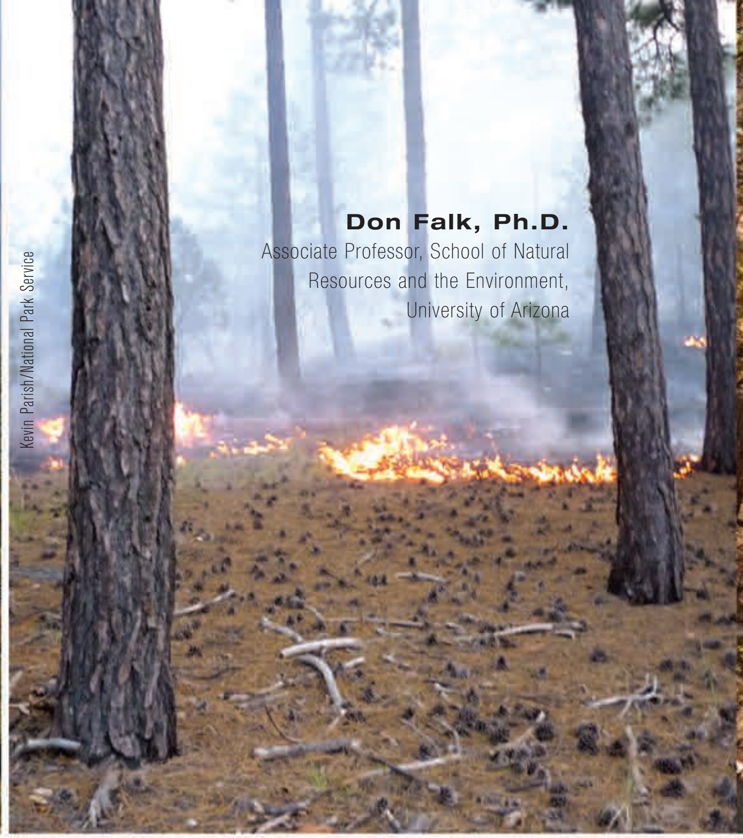
Solomon, S., D. Qin, M. Manning, et al, eds. 2007. "Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." In IPCC, 2007: *Climate Change 2007: The Physical Science Basis.* Cambridge University Press, Cambridge, United Kingdom, and New York, NY.

Weiss, J. L., C. L. Castro, and J. T. Overpeck. 2009. "The Changing Character of Climate, Drought, and the Seasons in the Southwestern U.S.A." *Journal of Climate,* Vol. 22.

Williams, P. C., Allen, C. Millar, et al. 2010. "Forest Responses to Increasing Aridity and Warmth in Southwestern North America." *Proceedings of the National Academy of Sciences,* USA, 107(50).

Fire: lessons of the past

Don Falk, Ph.D.
Associate Professor, School of Natural Resources and the Environment, University of Arizona



Above left: Fire tower in Sierra La Madera. Above right: Fire in the Rincons.

Above left: Surveying Sierra Cananea. Right: Fire in the Santa Catalinas.

Fire plays a keystone role in forest, woodland, and grassland ecosystems of the Sky Islands. Whether initiated by lightning or introduced by people, fire has been a constant presence here for thousands of years. As a consequence, many Sky Island species have evolved adaptations for surviving, and even thriving, with periodic exposure to wildland fire. However, the kind of fire we see today is in some respects unlike the fires of the past. Changing climate may make fire an even more pressing issue here.

Fire regimes—the properties and patterns of multiple fires in space and time—differ today from the regimes scientists have been able to reconstruct from historic records. The primary sources of deep-time historical records include tree rings, sediment charcoal, the age structure of old forests, and documentary evidence. What these sources tell us about the natural role of fire in the Sky Islands is remarkably informative and useful as we attempt to manage these precious ecosystems in a period of rapid changes in climate and land use.

Three important properties of fire regimes include fire frequency, fire size, and severity. In grasslands, woodlands, and open forests dominated by ponderosa and Arizona pine, fires occurred historically every three to ten years—frequently enough that species in these communities were strongly adapted to fire. Today, due to increased efforts to suppress fire, these ecosystems burn less frequently. In many cases, fire is kept out of the system for decades, allowing an excessive volume of woody fuels to accumulate. Fuels are stored energy, so when fuel accumulates, we set the stage for big, high-intensity fires.

Today, we hear about many fires that cover enormous areas—tens or even hundreds of thousands of acres. But this is not a new development; fires also burned over very large areas historically. For example, tree-ring reconstructions from many of the Sky Islands indicate multiple years per century when fires were detected at almost every sample point over the entire mountain range. In other words, large fires were a natural and regular part of the fire regime. So, what has changed?

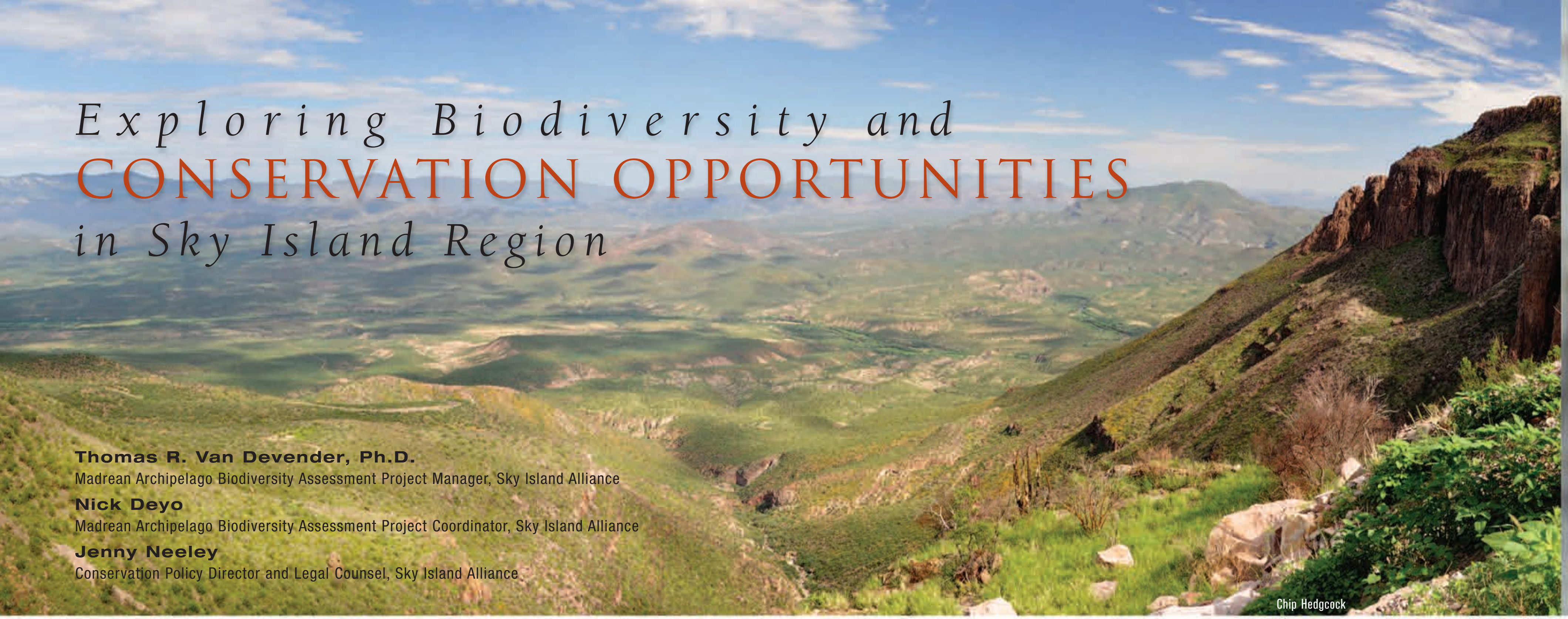
The key difference between fire regimes of the past and today lies in severity. Fire severity is a measure of the effect of fire on an ecosystem: killed trees, damage to soils, and loss of wildlife habitat. Over most mid-elevation ecosystems in the Sky Islands—oak woodlands and pine forests—extensive fires of the past were generally low-severity: fires were carried primarily by fine surface fuels such as grasses and needle litter, and relatively few large, mature trees were killed. (The exception to this generalization is high-elevation forests, which burned naturally with areas of high severity). But today, in the large wildfires we see on the evening news, a high proportion of the burn is of high severity, meaning that the effects on ecosystems are more damaging and long-lasting. Moreover, these high-severity effects are occurring in large contiguous patches of tens of thousands of acres, leaving few surviving trees and severely burned soils (which can kill soil organisms and make seed regeneration difficult). Severe fire effects on this scale impede ecosystem recovery and may set the stage for "tipping points" to novel ecosystems (such as shrublands and chaparral where forests once occurred).

What can we learn from these changes in fire regimes that will help us manage Sky Island woodlands and forests now and in the future? The primary lesson of landscape fire ecology is that we need to reintroduce fire as a natural ecosystem process. In most of our grasslands, woodlands, and mid-elevation forests, fire can help maintain ecosystems in a condition that facilitates their adaptation to current and future climate. Fires are likely to become more frequent and severe as climate change progresses in the Sky Island Region, driven by reduced winter rainfall, higher spring and summer temperatures, and longer fire seasons. Restoring natural fire regimes will help these ecosystems adapt and remain resilient in challenging times. S

SUGGESTED READING

Hudson, M. 2011. *Fire Management in the American West: Forest Politics and the Rise of Megafires.* University Press of Colorado, Boulder, CO.

Pyne, S. 2001. *Fire: A Brief History.* University of Washington Press, Seattle, WA.



Exploring Biodiversity and CONSERVATION OPPORTUNITIES in Sky Island Region

Thomas R. Van Devender, Ph.D.
Madrean Archipelago Biodiversity Assessment Project Manager, Sky Island Alliance
Nick Deyo
Madrean Archipelago Biodiversity Assessment Project Coordinator, Sky Island Alliance
Jenny Neeley
Conservation Policy Director and Legal Counsel, Sky Island Alliance

Above: Cruz del Diablo, Sonora

Above left: Canyon tree frog *(Hyla arenicolor)*. Right: Sonoran coral snake *(Micruroides euryxanthus)*.

Language meant to convey images and concepts often leads to inspiration and initiative. During a late nineteenth-century expedition along the U.S.-Mexico boundary, Lieutenant David Dubose Gaillard described the Arizona-Sonora borderlands as encompassing "bare, jagged mountains rising out of the plains like islands from the sea." Today it is called the Sky Island Region, an area of stunning landscapes globally recognized for its extraordinary biodiversity.

The biological richness of the Sky Island Region is almost visceral, immediately obvious to even casual visitors. The region's unique biodiversity stems from the convergence of five biotic influences: the Rocky Mountains from the north, the Great Plains and Chihuahuan Desert from the east, the Sonoran Desert from the west, and Sierra Madre Occidental as well as Neotropical influences from the south.

For over twenty years, Sky Island Alliance has worked to establish protected areas, connect wildlife pathways, restore healthy landscapes, and promote public appreciation of the beauty, richness and inherent value of this amazing region. We understand the Sky Islands from a biological perspective, where species and habitats do not recognize political boundaries, reinforcing the importance of ecoregional conservation. Connecting everyday people with hands-on science and conservation action, we are building bridges between communities and across political boundaries in order to explore, restore, connect, and protect this special place.

Biologists have been documenting the incredible biodiversity of this region, if sporadically, since the late 1800s, beginning with government-sponsored expeditions to survey the U.S.-Mexico boundary after the 1846 Mexican-American War and the 1853 Gadsden Purchase. Sky Island Alliance continues this legacy of discovery with the Madrean Archipelago Biodiversity Assessment (MABA). Since 2009 we have led seven major expeditions, most of them south of the border, to document plant and animal species throughout the Sky Island Region. The MABA database *(madrean.org)* provides public access to nearly 800,000 species records, including new records gathered during MABA expeditions, as well as historical records from museum collections, literature, field notes, and other databases. It serves as a primary source of biological information and images for conservation, land management, research, and education, and as a foundation for our work.

MABA's largest expedition to date was to the Sierra Bacadéhuachi in Sonora, 110 miles south of the Arizona border. This isolated range rises from the small town of Bacadéhuachi at 2,790 feet, to elevations over 6,000 feet, next to the main Sierra Madre Occidental, providing habitat for a diverse mixture of both temperate and tropical species. Like all MABA expeditions, this trip was a collaborative international effort, with 45 participants representing universities, agencies, and non-governmental organizations from both the United States and Mexico. Participants included botanists, entomologists, ornithologists, herpetologists, wildlife trackers, photographers, and support volunteers, all of whom worked tirelessly for four days to survey the flora and fauna of this rugged and remote mountain range in eastern Sonora.

The results from these surveys were no less than spectacular, reinforcing how much there is still left to learn about this region. In fact, this was the first herpetological survey in the Sierra Bacadéhuachi, and all of the observations were new for this range. We were excited to find the Tarahumara barking frog *(Craugastor tarahumarensis)*, pine toad *(Bufo occidentalis)*, and Chihuahuan mesquite lizard *(Sceloporus lemosespinali)*, all Madrean species found near Yécora, 100 miles to the south.

Similarly, bird records for this range had been sparse to nonexistent, and this expedition has helped fill a data gap in breeding bird distribution in Sonora. We observed the exact assemblage of species defining the breeding bird community of the pine-oak woodlands that make up the bulk of the northern Sierra Madre and much of the Sky Islands. Expedition birders were especially fortunate to observe the brown-backed solitaire, crescent-chested warbler, and buff-breasted flycatcher. Perhaps the

Above left: *Hamadryas atlantis,* a moth found in Foothills Thornshrub. Middle: Tom Van Devender pressing plants from the Patagonia Mountains. Right: Ridge-nosed rattlesnake *(Crotalus willardi).*

most thrilling discoveries were made by the expedition's elite team of entomologists. After working tirelessly day and night to collect specimens, their hard work paid off: seven new species of moths were discovered on this trip. Invertebrates such as insects and arachnids are the largest animal group and the least known, and our expeditions are providing invaluable invertebrate observations.

In addition to scientific research, MABA expeditions also provide important opportunities for cultural exchange between the United States and Mexico. On the Sierra Bacadéhuachi trip our group was accommodated at the Rincón de Guadalupe, a historic compound of gray adobe buildings among tall pines and cypresses terraced into the sides of a deep stream canyon in the Sierra. Originally serving as a hideout for priests during the *Guerra Cristera* of the early twentieth century, it is still managed by the Catholic Church, which gave us permission to use the site as a base camp. As a gesture of thanks, participants raised over $400 to purchase essential tools for the Rincón de Guadalupe.

On the last evening of the trip, pale light from a lantern and the sounds of the Madrean forest provided the perfect backdrop to talk about conservation. Rincón de Guadalupe, comprised of three properties that add up to 5,000 hectares, offers an ideal conservation opportunity in the Sky Island Region. Mexican participants spoke about forming a nonprofit organization to protect its historic buildings, while biologists suggested that protecting animals, plants, and vegetation as well would be a vision of conservation that might appeal to a broader group. While much work remains to be done, the conversations continue, and the enthusiasm of the group provides hope for the preservation of the cultural and natural history of this special place.

The work of the Sky Island Alliance is grounded in an intimate knowledge of this region's ecology and an understanding that successful conservation requires connections—between mountain ranges, across the landscape, and among communities, including those separated by political boundaries. Most importantly, conservation requires a connection between people and the place where they live. We are working to foster these connections in order to restore and protect the unique and awe-inspiring native biodiversity of this amazing region. S

SUGGESTED READING

U.S. Department of Agriculture. 1994. *Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northwestern Mexico. Conference Proceedings,* Tucson, AZ. U.S.D.A. Forest Service, SuDoc A 13.88:RM-GTR-264.

U.S. Department of Agriculture. 2013. *Biodiversity and Management of the Madrean Archipelago: Merging Science and Management in a Rapidly Changing World. Conference Proceedings,* Tucson, AZ. U.S.D.A. Forest Service, RMRS-P-67.

[VIDEO] MABA Sky Island Alliance 2013. Available at URL: http://vimeo.com/70008877.

Green Heron *(Butoride virescens).*

SKY ISLANDS

mountains sing of stone and ash
the desert, then, is the sea
lift up metamorphic
core
before
douglas-fir
before
a painted redstart
flitting
time
when one ecotone slides
into another
where ponderosa pine
where columbine
the forest calls
dream song
a hermit thrush in the wood

—Eric Magrane
ASDM Poet in Residence

Huachinera – sunset.

ARIZONA SONORA DESERT MUSEUM

2021 N. Kinney Rd.
Tucson, AZ 85743-8918

NON-PROFIT
ORGANIZATION
U.S. POSTAGE
PAID
ARIZONA-SONORA
DESERT MUSEUM