Sonorensis

Arizona-Sonora Desert Museum

CELEBRATING *Bats*

2011

Sonorensis
Arizona-Sonora Desert Museum

Volume 31, Number 1
Winter 2011
The Arizona-Sonora Desert Museum
Co-founded in 1952 by
Arthur N. Pack and William H. Carr

Craig Ivanyi
Executive Director

Rodrigo A. Medellín
Director of Science and Conservation
Managing Editor

Linda M. Brewer
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Martina Clary
Design and Production

Sonorensis is published by the Arizona-Sonora Desert Museum, 2021 N. Kinney Road, Tucson, Arizona 85743.

Sonorensis is published as a benefit to the Arizona-Sonora Desert Museum membership. It is intended to further our members' understanding of the Sonoran Desert Region and shape their sense of stewardship.

Visit us at www.desertmuseum.org

Cover: A lesser long-nosed bat approaching a cardon flower for its nectar. These and other nectivorous bats provide invaluable pollination services to many plants in Sonoran Desert ecosystems. Photo by Marco Tschapka.

Back cover: Ghost-faced bats form colonies of many thousands in caves; they are a powerful force in the control of insect pests. Photo by Rodrigo Medellín.

Thanks to all the photographers and organizations who contributed photos for this issue of Sonorensis *at no cost to further the cause of bat conservation, especially to the authors, their colleagues, and Bat Conservation International.*

Photo by Gerald Carter

Photo by Brock Fenton

Photo by Rodrigo Medellín

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Introduction

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Director of Science and Conservation, Arizona-Sonora Desert Museum and Senior Professor of Ecology, Instituto de Ecología, UNAM, Mexico

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This year, bats are a particularly timely subject; 2011–12 has been branded the *Year of the Bat* by the United Nations Environment Program and by EUROBATS, a European convention protecting bats on that continent. They did this for many reasons, foremost among them the growing threats to bats and the resulting urgency to close the wide gap between the common perception of bats as evil, dirty, disease-ridden, or dangerous, and the reality of bats as valuable species with vital roles in the web of life. At this juncture, for reasons you will soon learn, an enlightened public understanding of bats may be critical to their survival—and theirs to ours.

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Lesser long-nosed bats are effective pollinators of many plants.

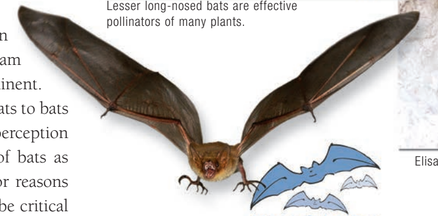

Photo by Rick Brusca

Elisabeth Kalko in the field in Sonora, Mexico.

Year of the Bat
2011-2012

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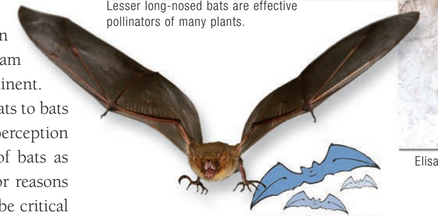

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California leaf-nosed bat

Photo by Angelica Menchaca

Photo by Winifred Frick

Townsends' big-eared bat

Photo by Winifred Frick

Hoary bat

Photo by Rodrigo Medellin

Common vampire bat

Photo by Rodrigo Medellin

Ghost-faced bat

Photo by Rodrigo Medellin

Mexican free-tailed bat

Photo by Rodrigo Medellin

Baja California fish-eating bat

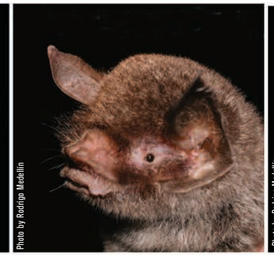


Photo by Rodrigo Medellin

Parnell's mustached bat

Photo by Rodrigo Medellin

Wagner's mustached bat

Rodrigo A. Medellin, Ph.D.
Director of Science and Conservation,
Arizona-Sonora Desert Museum and
Senior Professor of Ecology,
Instituto de Ecología, UNAM, Mexico

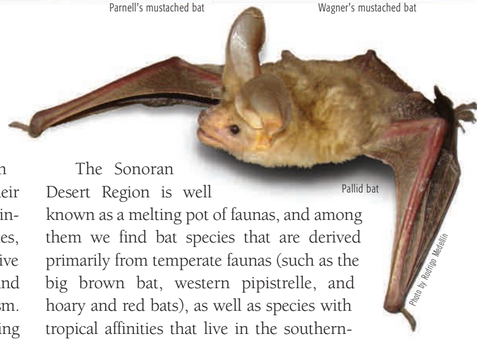
And **Karen Krebbs,** Conservation
Biologist, Arizona-Sonora Desert Museum

BAT DIVERSITY *in the* SONORAN DESERT

The Sonoran Desert Region, from southeastern California and Arizona to Baja California and Sonora, contains at least 48 species of bats—more than the total number of bat species in the entire United States. Almost all our bat species live in desert habitats, but some are exclusive inhabitants of the tropical areas of southern Sonora, and a few others typically inhabit boreal forests such as those on the sky islands. From south to north in the Sonoran Desert the number of bat species declines—with the greatest number in southern Sonora, the smallest in Arizona. From east to west, the number only changes slightly, with some species replacing others as we move into Baja California. These bats come in various shapes, sizes, and behaviors, with lifestyles that reflect the rich biological diversity of the region itself.

There are bats that fly very high above the vegetation and others that fly close to the ground. Some bats use rivers, streams, and washes as flyways, while others seek wide open spaces to search for their prey. There are bats with humongous ears, others with tiny ears. Some bats have a very long snout, and others a rostrum so short they look almost like monkeys. Some of our Sonoran Desert bats, like the mastiff bat or the Mexican free-tailed bat, have long, narrow wings that help them fly in the open at high speeds with relatively straight trajectories. Others, such as the little brown bat and the western pipistrelle, have shorter wings, which provide the amazing dexterity they demonstrate chasing moths and other prey in mid-air, following each swift twist and sudden turn. Still others, such as the pallid bat or the California leaf-nosed bat, have short, broad, powerful, and strong wings. This wing structure is ideal for the very slow flight they need to survey the ground or vegetation for prey. After landing on their prey and delivering several killing bites, they are able take off again carrying prey of up to 30 percent of their own weight.

In the Sonoran Desert a small group of species stay year-round, but most only take advantage of the plentiful resources the desert offers during the summer, migrating from central or southern Mexico to Sonora and Arizona. Although not yet verified, it is thought that some hoary bats and red bats can migrate annually all the way from Canada to Mexico and back. Some of the year-round Sonoran Desert residents hibernate in winter, lowering their metabolism to one heartbeat per minute and maintaining a temperature of 35º to 40º F. Other species, such as the California leaf-nosed bat, remain active throughout the winter where climates are mild and insects are available to fuel their high metabolism. These bats depend on "hot caves" and mines during colder periods. Some migrating bats, like lesser long-nosed bats, also make use of hot caves, which have chambers with elevated ceilings that trap the heat and maintain the temperature range bats need for reproduction. Newborn babies of these species also gather together in large numbers to keep warm.



Pallid bat

Photo by Rodrigo Medellin

The Sonoran Desert Region is well known as a melting pot of faunas, and among them we find bat species that are derived primarily from temperate faunas (such as the big brown bat, western pipistrelle, and hoary and red bats), as well as species with tropical affinities that live in the southernmost skirts of the region (such as the hairy fig-eating bat, funnel-eared bat, Gray sac-winged bat, ghost-faced bat, and the mustached bat). Several species have evolved as unique endemics to the Sonoran Desert, including the fish-eating bat of the Sea of Cortez and the California leaf-nosed bat.

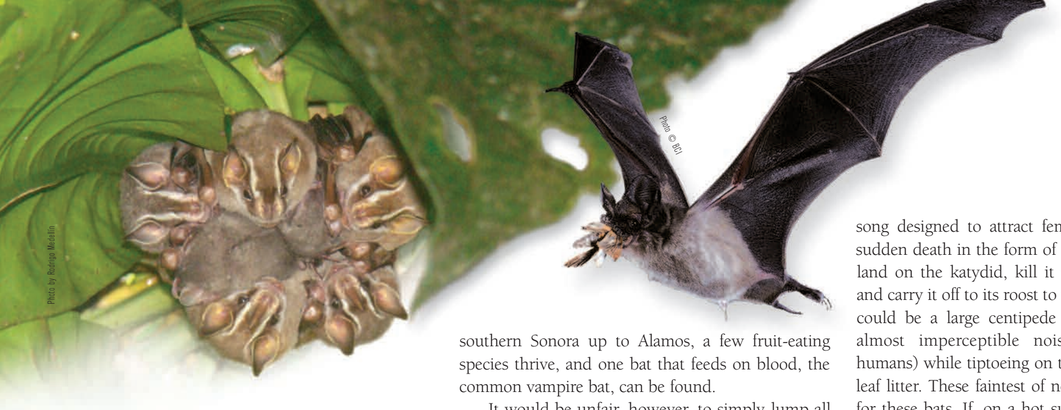


Photo by Rodrigo Medellín

Photo © BIO

Top: Bats have adapted to many habitats. These cute little bats from Costa Rica, Watson's fruit-eating bats *(Artibeus watsoni)*, make tents out of large tropical leaves. Above: ASDM docents host a regular bat-emergence event at the bridge near Campbell and River Roads in Tucson. Cut out: Mexican free-tailed bats feed on moths and other soft-bodied insects.

TIME TO EAT:
Their Special Diets and What They Mean

The Sonoran Desert Region is home to many insectivorous bats, as well as nectar feeders and the unique fish-eating bat. In the more tropical habitats from southern Sonora up to Alamos, a few fruit-eating species thrive, and one bat that feeds on blood, the common vampire bat, can be found.

It would be unfair, however, to simply lump all the bats that feed on insects and other arthropods in one category. Some species, such as the Mexican free-tailed bat, specialize in feeding on moths, flies, and other soft-bodied insects, taking them on the wing (while both are flying). One of the most visible bats in our region, the Mexican free-tailed bat roosts in large to huge numbers; one cave near Carbó, Sonora, contains over five million bats, and the bridge near Campbell and River Road in Tucson, Arizona, contains tens of thousands. Free-tails are "swarm feeders" that fly through large groups of insects. One million of these bats destroy *ten tons* of insects every night! This in itself is such a remarkable service to ecosystems and to humans that it is hard to imagine a world with no insect-eating bats. Other species, like the big brown bat, feed on beetles and other hard-bodied insects on the fly.

But there are others, such as the pallid bat and the California leaf-nosed bat, that specialize in capturing arthropod prey on the ground or vegetative surface, cueing in on sounds produced by the prey. A katydid grasshopper happily singing its summer song, a love song designed to attract females, is also attracting sudden death in the form of a powerful bat that can land on the katydid, kill it with a couple of bites, and carry it off to its roost to savor a tasty meal. Or it could be a large centipede or a scorpion making almost imperceptible noises (certainly for us humans) while tiptoeing on the sand or under some leaf litter. These faintest of noises herald "mealtime" for these bats. If, on a hot summer night, you have occasion to observe life under a big light, you will see that the light attracts lots of flying insects that then fall to the ground, in turn attracting centipedes, scorpions, and large spiders. If you watch, you will undoubtedly see bats hawking the flying insects overhead. Closer to the ground, bats that eat terrestrial arthropods will pass through, selecting their next unsuspecting prey as if at a buffet dinner.

Other bat species feed primarily on nectar and pollen from several plant species— from columnar cacti like saguaro, cardon, and organ pipe, to agaves and morning glory trees. Most of these plant-loving bats are migratory. You may have noticed them visiting your hummingbird feeders, primarily in August (although some Mexican long-tongued bats remain in southern Arizona in the winter and also rely on hummingbird feeders during the colder months). These fascinating animals have an intimate connection with the desert plants: over many centuries the vast majority of the pollination of these columnar cacti and agaves has been carried out by bats. In other words, our familiar landscape with its striking, enormous cacti, is the result of millions of years of connections between bats and plants.

The great majority of the nectar bats in our region are females bearing or suckling young, since the males remain behind in western Mexico. These females carry out migrations of more than a thousand miles as a bat flies, from west-central Mexico, around the coast of Jalisco near Puerto Vallarta and farther south, all the way up to Sonora and Arizona. It is hard to believe that this demanding trip is fueled only by nectar and pollen! And in their long migration, they provide important benefits to humans. Their pollination of agave is essential not only to the ecosystems, but to many humans too. Agaves are the source of many useful products—from natural ropes and string to syrups, to the larvae of a moth used as food in central Mexico, to tequila, mescal, and other beverages. Many millions of dollars are derived from the relationship between bats and agaves; in fact, tequila sales represent almost one billion dollars annually.

A few bat species in the southern end of the region feed on the fruits of tropical trees such as the native fig tree, dispersing its seeds and ensuring that the next generation of trees will be part of the tropical dry forest. One species endemic to the Sea of Cortez, the fish-eating bat, spends its entire lifetime on islands of the Gulf. It forages over the waves of the sea, never drinking fresh water. This remarkable bat is large,


Photo © BIO

Lesser long-nosed bats pollinate an agave. Right: Mexican free-tailed bats form tight clusters on the ceiling of a cave. Cut out: Shot of tequila with limes. Tequila is made from agave plants.

among the largest bats in our region, with a wingspan of about 17 inches and weighing almost an ounce. Its feet have elongated, flattened, recurved sharp claws, with which they hook fish and aquatic invertebrates from the ocean surface.

SURVIVAL STRATEGIES
Tailored to Place

Along with their great diversity in shapes and diets, bats have evolved wide-ranging survival strategies. All bat species in the Sonoran Desert use the sophisticated echolocation system for which they are renowned. Some rely on it to locate tiny insects in mid-air, others to navigate in and out of their roosts or to find their way through forest understory. Interestingly, preliminary evidence hints that even nectar bats, which have not generally been known for their use of echolocation, use it to find flowers. Some bats have color vision, some black-and-white vision. Where and how they roost depends on where they evolved and the resources available to them—from cavities in trees and cacti to rock crevices, to bark, leaves, and manmade structures. Most bats have two types of roosts, one in which to rest during the day and the other in which to eat and digest food during the night's foraging activity. Bats hanging on your front porch wall during the night will usually be absent during the day.


Photo by Rodrigo Medellín

NOT JUST "A BAT"

With this brief overview, we hope to have passed on to you our enthusiasm and appreciation for the extraordinary diversity of bats in the Sonoran Desert Region, not only in the number of species, but also in their morphology, food habits, behaviors, and above all, the remarkable services they provide to ecosystems and to us. Next time you are out enjoying a splendid desert evening and see a bat chasing a moth, or see one visiting your hummingbird feeder, you might say quietly, "Thank you, friend." S

BATS OF THE SONORAN DESERT REGION

In the order Chiroptera, worldwide, there are approximately 1,200 known species of bats. In the Sonoran Desert Region, there are at least 48. Here, we list bat species found in Sonora, Baja California, the islands of the Gulf, and the stateside portion of the Sonoran Desert.

Photo series by Marco Tschapka

Above series of photos: Pallas's long-tongued bat drinking nectar from a morning glory tree.

Common Name	Species	Distribution	Diet
Free-tailed Bat Family *(Molossidae)*			
big free-tailed bat	*Nyctinomops macrotis*	C & N Mexico & S US	I
greater mastiff bat	*Eumops perotis*	C & N Mexico & S US	I
Peale's free-tailed bat	*Nyctinomops aurispinosus*	Tropical	I
pocketed free-tailed bat	*Nyctinomops femorosaccus*	C & N Mexico & S US	I
Underwood's mastiff bat	*Eumops underwoodi*	W Mexico & SW US	I
Funnel-eared Bat Family *(Natalidae)*			
(No common name)	*Natalus lanatus*	Endemic to W Mexico	I
Mexican greater funnel-eared bat	*Natalus mexicanus*	Tropical	I
Ghost-faced or Mustached Bat Family *(Mormoopidae)*			
Davy's naked-backed bat	*Pteronotus davyi*	Tropical	I
ghost-faced bat	*Mormoops megalophylla*	Tropical	I
Parnell's mustached bat	*Pteronotus parnellii*	Tropical	I
Wagner's mustached bat	*Pteronotus personatus*	Tropical	I
New World Leaf-nosed Bat Family *(Phyllostomidae)*			
California leaf-nosed bat	*Macrotus californicus*	NW Mexico & SW US	I
common vampire bat	*Desmodus rotundus*	Tropical	B
hairy fruit-eating bat	*Artibeus hirsutus*	Endemic to W Mexico	FR
highland yellow-shouldered bat	*Sturnira ludovici*	Tropical	FR
lesser long-nosed bat ■ ●	*Leptonycteris yerbabuenae*	Mexico & SW US	N & P
little yellow-shouldered bat	*Sturnira lilium*	Tropical	FR
Mexican long-nosed bat ■ ● ▲	*Leptonycteris nivalis*	Mexico & SW US	N & P
Mexican long-tongued bat ■	*Choeronycteris mexicana*	Mexico & SW US	N & P
Pallas's long-tongued bat	*Glossophaga soricina*	Tropical	N & P, I
Toltec fruit-eating bat	*Artibeus toltecus*	Tropical	FR
Waterhouse's leaf-nosed bat	*Macrotus waterhousii*	Tropical	I
Sac-winged Bat Family *(Emballonuridae)*			
gray sac-winged bat	*Balantiopteryx plicata*	Tropical	I

Common Name	Species	Distribution	Diet
Vesper Bat Family *(Vespertilionidae)*			
Allen's big-eared bat	*Idionycteris phyllotis*	C and N Mexico & S US	I
Arizona myotis (or occult myotis)	*Myotis occultus*	C and N Mexico & S US	I
Baja California fish-eating bat ◆	*Myotis vivesi*	Islands near Baja	F & I
big brown bat	*Eptesicus fuscus*	North America	I
California myotis	*Myotis californicus*	Mexico & W US	I
cave myotis	*Myotis velifer*	Mexico & S US	I
cinnamon myotis	*Myotis fortidens*	Tropical	I
fringed myotis	*Myotis thysanodes*	Mexico & S US	I
hoary bat	*Lasiurus cinereus*	North America	I
little yellow bat	*Rhogeessa parvula*	Endemic to W Mexico	I
long-legged myotis	*Myotis volans*	C and N Mexico & S US	I
Mexican big-eared bat	*Corynorhinus mexicanus*	Endemic to C & N Mexico	I
Mexican free-tailed bat	*Tadarida brasiliensis*	Tropical & temperate	I
pallid bat	*Antrozous pallidus*	C & N Mexico & C US	I
peninsular myotis ▲	*Myotis peninsularis*	S Baja California	I
silver-haired bat	*Lasionycteris noctivagans*	North America	I
small-footed dark-nosed myotis	*Myotis melanorhinus*	C & N Mexico & S US	I
Southwestern myotis	*Myotis auriculus*	C & N Mexico & S US	I
spotted bat	*Euderma maculatum*	C & N Mexico & W US	I
Townsend's big-eared bat	*Corynorhinus townsendii*	C & N Mexico & S US	I
Western long-eared myotis	*Myotis evotis*	Baja California & CA	I
Western pipistrelle	*Pipistrellus hesperus*	C & N Mexico & S US	I
Western red bat	*Lasiurus blossevillii*	W Mexico & SW US	I
Western yellow bat	*Lasiurus xanthinus*	C & N Mexico & S US	I
Yuma myotis	*Myotis yumanensis*	C & N Mexico & S US	I

Conservation status: ■ Threatened in Mexico ● Endangered in the US ◆ Endangered in Mexico
▲ Endangered according to International Union for the Conservation of Nature (IUCN)
I = insects F = fish N = nectar P = pollen FR = fruit B = blood

ISLAND BATS on the Sea of Cortez

Winifred F. Frick, Ph.D.
National Science Foundation Bioinformatics Postdoctoral Fellow, University of California Santa Cruz and Boston University

Photos by Rodrigo Medellín

Photo by Marco Tschapka

Top: Gulf of California islands harbor many endangered species, including the endemic Baja California fish-eating bat. Above and cut out: Huge, elongated claws help these fish-eating bats capture fish and invertebrates on the sea surface.

Sunset on a desert island is a magical experience, as the heat of the day subsides with the setting sun and nocturnal life awakens. On an island in the Sea of Cortez, you might see bats flitting overhead as they emerge from crevices and caves to forage in the night sky. At least twelve species of bats are known to live on these islands, where they make up a large proportion of the native mammalian diversity.

Most islands in the Sea of Cortez, also known as the Gulf of California, have at least a few species of bats, with smaller and more isolated islands harboring the fewest. The diversity of bat species is higher in the southern part of the Gulf, where more rain falls during the monsoon season, contributing to a greater diversity of vegetation and habitat types. This gradient in bat diversity is similar to patterns of bird diversity in the same archipelago. Foraging habits likely influence the distributional patterns of these island bats, and insectivorous bats typically don't live on islands of less than 100 hectares unless they are very close to the peninsular coast.

Bats on these desert islands, as elsewhere, provide vital ecological services ranging from reducing insect populations to pollinating plants and dispersing seeds. A federally endangered species in both the United States and Mexico, the lesser long-nosed bat is one of the most common bats on the islands. Caves on several islands support large maternity colonies of lesser long-nosed bats, which are important pollinators for the picturesque cardón cactus *(Pachycereus pringlei)*. The sweet nectar in cardón flowers also supplements the diet of the pallid bat, which normally feasts on scorpions and other ground arthropods. But most bats on these islands are insectivores that hunt aerial insects such as moths and beetles. Another common island resident, the California leaf-nosed bat, specializes in gleaning insects off plant surfaces.

There are no species of bats endemic to the islands, but there is one island species endemic to the region—the Baja California fish-eating bat. Unique to northwestern Mexico, the fish-eating bat is true to its name, with a predilection for devouring fish. It hunts over calm sea waters at night using echolocation to detect ripples in the water's surface, snaring small fish with its unusually large feet. This species is common on all the Gulf islands; it also inhabits a few islands on the Pacific coast of the Baja California Peninsula but is found nowhere else in the world. It commonly roosts under rocks and in rocky crevices close to the water's edge. One well-studied population inhabits Isla Partida in the Midriff, where several thousand bats roost in rocky interstices underneath a colony of storm-petrels. Female fish-eating bats give birth to a single pup in the spring, and carry their young to convenient night roost caves to wait while they forage out over the sea.

The islands in the Sea of Cortez have served as a natural laboratory for studies on marine and terrestrial ecology for many years, but until recently very little research has been focused on its bats, and many questions remain about the ecology and conservation of bats on islands. Future research on their dispersal and movement among the islands will help determine whether island populations are distinct or connected to coastal populations. Most islands in the Gulf are protected by Mexico's national park system, which shields their bat populations from threats of human disturbance and habitat destruction. However, introduced predators like rats and cats may pose risks to the endemic fish-eating bat, which is unaccustomed to these invasive predators. S

Photo by Rodrigo Medellín

CHIROPTERAN MIGRATIONS
in the Borderlands

Rodrigo A. Medellín, Ph.D.
Director of Science and Conservation,
Arizona-Sonora Desert Museum and Senior Professor of Ecology,
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The well-being of neighboring countries depends in part upon the migrants between them. Movements across borders, whether of wildlife, people, or products, are often beneficial to both countries.

Take the case of bats along the U.S.-Mexico border. At least 34 bat species inhabit the 2000-mile-long transborder area from Texas to California and from Baja California to Tamaulipas. More than a dozen and possibly up to 20 species migrate from central and southern Mexico to this region for the summer and then return south in the fall, including many millions of insectivorous Mexican free-tailed bats and hundreds of thousands of nectar-feeding bats such as the lesser long-nosed bat and the Mexican long-nosed bat. Fortunately, there is no wall or boundary of any kind, or safety issue, or regulation that can stop them.

Baby lesser long-nosed bats cluster together on the roof of a cave to take advantage of body heat.

Cut out right: Saguaro cactus in bloom.

What would happen if these bats were unable to migrate? Crops in the border region, such as cotton, corn, and other vegetables, would suffer multimillion-dollar losses due to crop pests whose populations would grow unchecked. In time, the native landscape of our charismatic Sonoran Desert would also show severe changes. Although other animals carry out some pollination service for saguaros, organ pipe, and other columnar cacti, bats are essential to their reproduction and genetic diversity, carrying pollen from one plant to others up to ten or more miles away. In fact, feces analyses show that hundreds of thousands of bats roosting in the Pinacate region each summer fly 13 or more miles regularly to feed in and pollinate saguaro flowers close to the border.

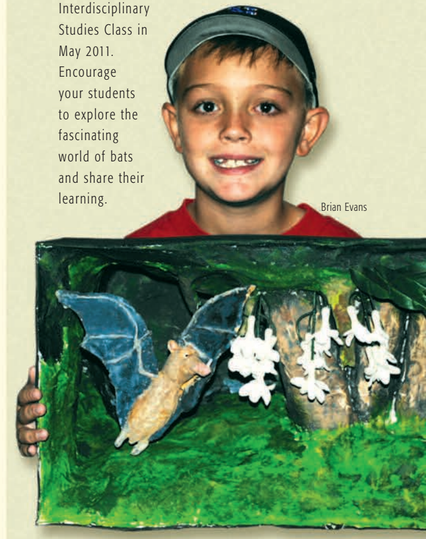
Nectar bats come to the transborder region during the summer because the hot caves they inhabit in our desert region provide them hospitable conditions (including 90°-plus ambient temperatures) for giving birth and rearing offspring. Because they are unable to regulate their body temperature, babies of Mexican free-tailed, Mexican long-nosed, and lesser long-nosed bats, among others, require environments that are as hot as their parents' bodies to survive. So these bats gather in large colonies, producing body heat that gets trapped against the roof of the cave in which they roost.

Most people are not aware of the important roles bats play in maintaining healthy ecosystems and productive crops. Nor do they realize what sensitive creatures they are, or that they can be severely affected by disturbances to their roosts and habitats, including the critical migratory corridors they rely on to travel between Mexico and the United States. Both the U.S. and Mexican governments and private citizens in both countries need to be proactive in securing the long-term health of bat populations in the border region and throughout their ranges. Laws and policies safeguarding habitats, caves, and bats (beyond just the endangered species) are important in achieving this protection. Real protection will take collaborative, government-recognized efforts between both countries. Only an organized, well-designed strategy that brings together citizens, conservationists, government agencies, and bat biologists on both sides of the border can achieve this.

Strong awareness campaigns, educational programs, effective and continuous communication with the federal governments (with all ten border states) are imperative. In southern Mexico, bat biologists have worked in rural elementary schools, providing "bat-pollination" and other games for schoolchildren who previously had known little about and had little sympathy for bats. Years later, when the educators returned, those children's younger siblings already knew about the habits and importance of bats. The teachers and children were passing the information on. There is hope. But there is much to do, and everyone can play a role. Write to your legislators, talk to your leaders, your family, and your friends, and support organizations that work to protect bats. Every contact is important in spreading the word. We must build a critical mass large enough for both countries to act, and we need to start now. S

KID POWER!

Your children can help get the word out, too. When students at Tucson's Sunrise Drive Elementary School were asked to do a report on endangered animals, fourth-grader Brian Evans chose to learn and write about bats. His report "Banana Bats Go Bananas" took a creative angle on telling the story of this endangered nectar-loving bat of the central Pacific coast in Mexico. He imagined two bats "talking" as they observed our bat biologist, Dr. Rodrigo Medellín, doing his research. Brian also built a three-dimensional model of the bat hovering by its favorite meal, which was displayed at the open house of his Interdisciplinary Studies Class in May 2011. Encourage your students to explore the fascinating world of bats and share their learning.



Brian Evans

Photo © BIO

A Waterhouse's leaf-nosed bat has captured a katydid.

ECHOLOCATION:
How Bats "See" the World

Tania Gonzalez-Terrazas, biologist, and **Elisabeth K.V. Kalko, Ph.D.,** Professor, University of Ulm, Germany

The two main evolutionary adaptations that have made bats so successful in populating the nocturnal niche are echolocation and active flight. While bats are unique among mammals in their ability to actively fly, a few other mammals, such as some shrews, toothed whales, and dolphins, use echolocation. But most nocturnal vertebrates are highly dependent on visual cues for finding their way in the dark, and most bats are not. Echolocation allows them to navigate in space and, in many cases, to detect, identify, and locate food in total darkness. Echolocation is a form of biological sonar in which an animal emits high-frequency calls and extracts and interprets information from the returning echoes to navigate and forage.

Depending on where and what they eat and how they acquire their food, bats confront a variety of sensorial challenges. For example, bats that hunt insects on the wing in open space or at forest edges (aerial insectivores) face different conditions than those that search for prey within dense vegetation or take food from the ground or from a water surface (gleaning and trawling bats). Bats flying close to or within vegetation have to discriminate between echoes from potential food items and the multitude of echoes bouncing back from leaves, twigs, and the ground. Often, echoes from sources of food and the ambient background overlap and make the extraction of relevant information difficult for the bats. In that case, bats may use additional cues, such as scent or noises produced by the prey.

The sonic structures of the echolocation calls bats emit also show remarkable diversity, depending on the species of bat and its hunting strategy. Bats have evolved a wide variety of signal types that differ in frequency, duration, harmonic content, and sound pressure (intensity). The general design of the outgoing call determines the type and quality of information contained in the returning echoes. Many bats can change signal structure to accommodate a behavioral situation, habitat, or foraging strategy. Search calls emitted when bats are looking for food differ from approach calls produced while a bat is approaching a target. Aerial insectivores typically emit many very short calls in rapid-fire repetition during the final stage of pursuit, prior to capturing their prey or an attempt to capture.

Echolocation calls often consist of several elements, each providing the bat with a different kind of information. Frequency-modulated broadband signals are well suited for precise target location, whereas narrowband signals facilitate the detection of moving prey. The trade-off between basic detection and precise location is reflected in call structure, as bats that have to perform several tasks simultaneously combine broadband and narrowband elements in their signals.

Whereas call features such as bandwidth, intensity, duration, and pulse interval are mainly dictated by the sensory challenges faced by the bats, other parameters such as peak frequency, harmonics, and sequence of signal components are dictated by phylogenetic differences in the bats. Sometimes echolocation calls are species-specific, which in some areas and situations allows us to identify some species by call.

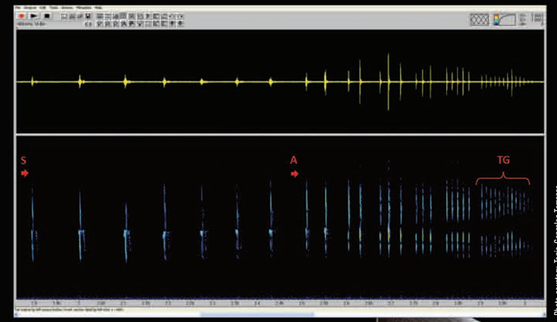


Photo courtesy Tania Gonzalez-Terrazas

A sonogram showing the echolocation behavior of a lesser long-nosed bat approaching a cactus flower. In it, three different phases of emissions are identified: search (S), approach (A) and a distinctive terminal group (TG) that the bat emits before the insertion of the snout into the flower (Gonzalez-Terrazas et. al., in preparation). Right: A pygmy fruit-eating bat *(Artibeus phaeotis)* from western Mexico carrying a tropical fig.

Photo by Angelica Menchaca

Because so much information about foraging behavior, activity, and identity of bats can be derived from the shape and pattern of their echolocation signals, bat researchers increasingly use echolocation as a tool to address relevant questions. Acoustic monitoring permits us to document the presence or absence of a species, as well as its foraging activity, particularly in aerial insectivores that have, so far, been seriously understudied. Recording and analysis of echolocation calls provides detailed information on the habitat use and activity patterns of many species, so acoustic monitoring has become an important component of bat surveys and behavioral studies. These studies open up new perspectives for long-term monitoring programs, and will undoubtedly provide an excellent base for the establishment of comprehensive programs for bat research and conservation. S

Karen Krebbs with lesser long-nosed bat.

Karen Krebbs, bat biologist at the Desert Museum, uses both acoustic monitoring and mist netting in her research. Over the last 12 years, she has monitored bats in northern Mexico; in the Chiricahuas, Huachucas, and other sky islands of southern Arizona; at the Muleshoe Ranch; in Aravaipa Canyon; and in several National Parks, including Organ Pipe and Tumacácori. She has also monitored in the Tucson vicinity, including the Sweetwater Wetlands and Agua Caliente Park. The extensive data she has gathered is currently being compiled into a database for the National Park Service, Arizona Game and Fish Department, and The Nature Conservancy. S

Chinese bat circle pedestal.

Photo by Rodrigo Medellín

BATS & PEOPLE

Photo courtesy of J. D. Pettigrew, Professor Emeritus, Queensland Brain Institute.

Laura Navarro
Environmental Education Specialist, PCMM/Bioconciencia, Program for the Conservation of Mexican Bats

Bats and human beings have been living together ever since *Homo sapiens* has walked this planet. Over the millennia, bats have been influencing not only our ecosystems but also our perspective of nature, our beliefs, and our behaviors. In many cultures across the globe bats play a crucial role in religion, art, or literature; they have also been the subject of consequential scientific investigations. Exploring our past helps us understand how important these extraordinary flying mammals have been to humans.

ANCIENT & OLD WORLD

Representations of Bats

We find representations of bats in many ancient cultures. One of the earliest indications of the importance of bats in the lives of our late Palaeolithic ancestors was recently found near Kalumburu, Australia; eight beautifully painted white-striped flying foxes, a type of fruit bat, have been roosting peacefully in a cave for more than 20,000 years.

Some of the most amazing representations, dating from about 2,000 BCE, are in the tomb of Baket III in Egypt, where bats surrounded by birds were carefully detailed, allowing us to assume that whoever crafted them had the opportunity to observe them closely.

Bats also make an appearance in some of the greatest literary works in history. In Homer's *Odyssey,* Hermes speaks of bats hanging from their legs and living in groups. In *Metamorphosis,*

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Courtesy New York Public Library digital gallery

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Photo by Rodrigo Medellín

Opposite page top: Cave paintings of white-striped flying foxes more than 20,000 years old, found near Kalumburu, Australia. Above, in order from left to right: Traditional wooden decorative plaque depicting Chinese symbols of prosperity, including the character "Fu" and the bat, whose name is pronounced similar to "Fu," ie a visual pun; Archeological recordings from *I monumenti dell'Egitto e della Nubia* (1832-1844) by Ippolito Rosellini depicting art in an ancient Egyptian tomb, including drawings of anatomically correct bats; A fountain featuring a bat in Rome, Italy, dating from 1586, restored in 1733; Chinese golden carved bat in the Forbidden Palace, Beijing. Below right: A bat profile shows up in the Mayan glyph in the corner of this inscription. The bat glyph is common in the Classic Mayan period.

Ovid recounts a Greek myth in which the three daughters of King Minyas of Orkhomenos, the Minyades, were transformed into bats after refusing Dionysus's command to join an orgy.

In one of Aesop's fables, a bat is caught twice by a weasel but cleverly escapes, first by telling the weasel he was a mouse and then that he was a bird. In another fable, a bat loses all its money after a shipwreck, and to avoid conflict with its associates, it has been hiding during the day ever since then. In a third fable, a bat hesitates about whether to join the army of the beasts or the army of the birds and ends up alone. These stories are fanciful explanations of chiropteran or bat characteristics.

Aristotle correctly classified bats as warm-blooded animals, and he concluded that when bats leave their roosts in large groups, the following day would be warm and calm, but when they hide and do not appear at sunset, a stormy or a cloudy day would follow. In fact, bats are less active on stormy nights than on calm and dry nights.

POPULAR MYTHS

During the Middle Ages, bats were considered mysterious and evil creatures associated with witchcraft and sorcery; they represented messengers of the Devil. Because bats were difficult to notice and catch, people believed they had the ability to become invisible; some people even believed that hanging a bat's eye around one's neck would grant that person the power of invisibility.

As ridiculous as these ideas might seem to us nowadays, current misconceptions about bats are equally unfounded. Bats are still poorly understood by the general public, and some myths still hold sway. For example, it is common to hear that bats are blind and hairless creatures that transmit fatal diseases to man, or that they bring bad luck, or that they attack women's hair. It is almost shocking to know that they are still used as key ingredients in potions concocted to make a person fall in love or to punish someone.

Undoubtedly, the Bible has influenced attitudes toward bats in western cultures. In Leviticus (11:13–19) and in Deuteronomy (14:11–18) bats fall under the umbrella of abhorrent, unclean birds that men should detest and avoid eating (as do vultures, sea gulls, raptors, and long-legged birds, among others). In the Talmud, a book of Hebrew religious teachings, several passages describe the nature of bats. For example, in one Bava Qamma it states that after seven years hyenas turn into bats and after additional seven-year periods they turn into thorns and demons. Another entry says that bats live for 30 years, lay eggs, and drink milk. As mammals, baby bats do drink milk, of course, and although some bats may have lived up to 30 years, few species have a lifespan of more than 10 to 20 years; and no bats lay eggs.

Photo courtesy of Laura Navarro.

Courtesy the Metropolitan Museum of Art, New York.

Photo by Rodrigo Medellín

Photo by Laura Navarro

BATS IN THE PRE-COLUMBIAN NEW WORLD:

Perceptions and Iconography

Representations of bats in the New World have been found in buildings, crafts, and paintings of ancient cultures. Some of the most remarkable include the zoomorphic figurines of the pre-Columbian Toltec culture found in the Palace of Tetitla, about 30 miles north of Mexico City, and in the traders' neighborhood of Teotihuacan. According to an iconographic analysis, these figurines represent real chiropterans. Archaeologists also found a ring used for the Mesoamerican ballgame in Xochicalco crafted in the shape of a bat. And more recently, a large ceramic figure more than six feet tall was found in Miraflores, Morelos, at the foot of the Popocatepetl Volcano. It has a bat head with a human body, and the clawed feet and the hands of a bat. According to archaeologist Francisco Hinojosa, this figure represents a Bat God.

One of the most representative pieces of the Zapotec civilization is without doubt the jade burial mask found in Monte Alban, Oaxaca, which displays the characteristic shape of leaf-nosed bats. It is considered one the most important representations of the Bat God, and is an extraordinary piece of Mayan history and art. Funerary urns, including two representing *Piquete Ziña,* the Bat God, also came from the Zapotecan culture, and several bat-themed ceramic pieces found in central Veracruz from the Classical Period (600–1500 AD) are on display in the Anthropology Museum of Xalapa, Veracruz.

There are many representations of bats in the Mayan culture. One of the most impressive is the sculpture *Qaaw'a Sotz,* "Lord Bat" in the Q'eqchi' Maya language, found at Copan. It represents a mythic being with human body, bat head, and wings, dressed with a loincloth that hangs down to its feet. Another beautiful piece is a whistle in the shape of a bat found at Jaina Island, Campeche. Paintings on ceramic pieces are also common in Mayan art, such as a plate with a painting of four bats recently found in Balam-Kú, Campeche. During the Classical Period (450 AD) Mayans produced intricate relief carvings that either adorned buildings or stood alone as stelae; some of these take the shape of bat heads. In addition, the hieroglyphic symbol of the City State of Copan is the face of a bat, clearly identifiable by the leafed nose and the tragus.

In the Haab', the Mayan solar calendar of eighteen months, each month had a patron god that influenced each day with its particular supernatural powers. During the month of *Tzotz,* "The Bat God," beekeepers prepared themselves for the coming activities by fasting. It may have also been associated with the beginning of the darkest months of the year in the winter.

Though bats are frequently represented in Mesoamerican codices, it is difficult to establish the connections they had with other gods and the role they played in the Mesoamerican way of thinking. In the Fejé Èrváry-Mayer Codex, the Vaticanus Codex, and the Borgia Codex representations of the man-bat, better known as *Tzinacantli,* the Nahuatl word for bat, relate to beheadings and death. The *Mapa Tlotzin,* a painted manuscript, tells the story of a Nahua group from its settling to the reign of Nezahualpilli. In one of the paintings a bat stretching its wings hangs at the top of a cave.

The sacred Mayan books, The Book of *Chilam Balam* and *The Popol Vuh,* contain numerous stories and descriptions of bats. In these books, both caves and the Mesoamerican ballgame represent the entrance to the underworld; in the game, the losing team was decapitated as a ritual sacrifice for the gods. Bats were commonly associated with the underworld and played a role as decapitators in some of the characters of the books.

FACTOID

Feeding on blood is not unique to bats, but is a fairly common strategy used by many arthropods, as well as some human cultures such as the Masai in Africa.

Top left: Etching by Francisco Goya, "The Dream of Reason Produces Monsters," from Caprices, No. 43. 1796. The message in Spanish reads, "Fantasy abandoned by reason produces impossible monsters: united with her, she is the mother of the arts and the origin of their marvels." Left: Decorative stone carving in in the Summer Palace, Beijing, China. Cut out above: Pre-Columbian ceramic figure of a bat from Los Cerros, Veracruz, on display at the Museum of Anthropology at Xalapa.

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Photo © George DeLange

Photo by Rodrigo Medellín

BAD BATS, GOOD BATS

Europeans arriving in the New World also chronicled bats. Some observers described insectivorous bats and some told stories of larger and "tasty" animals, which may refer to frugivorous bats. One kind of bat, however, was particularly described: the hematophagous, or vampire, bats. They told how these animals bit humans on their toes and how calves bled to death after being attacked by vampire bats. Not surprisingly, sensational reports of this sort spread, raising fears and leaving little sympathy for any bats in the public conscience, if not engendering an active desire to kill them.

One of the most influential twentieth-century literary works was Bram Stoker's 1897 book, *Dracula,* one of the most famous horror novels of all time. Interestingly, Stoker played on two anecdotes from articles he'd reviewed, one of which was a newspaper article with a description of a vam-

Top right: Detail of a bat on the top of Mercado de Colón in Valencia, Spain. A bat *(Rat Penat)* is the animal in Valencia's coat of arms and it appears in multiple representations throughout the city. Middle: Decorated door of a temple in Laos. Cut out: The Jade Mask of the Bat God is a splendid example of Zapotec archeology and art. It was found in Monte Alban, Oaxaca. Right: Chinese green gate with carved bats, Summer Palace, Beijing, China.

Photo by Rodrigo Medellin

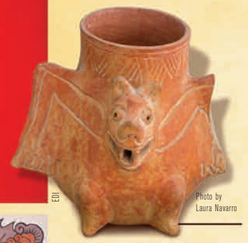

Photo by Laura Navarro

"As they sought the dark,
a skinny membrane spread down
their dwarfed limbs and wrapped thin wings
about their tiny arms....
Not with feathered plumes they ride the air,
but keep themselves aloft on parchment wings,
and when they try to speak
they send a tiny sound that suits their
size....
From dusk they take their name
and flit by night."

—Melville translation of Ovid's "The Daughters of Minyas" from *Metamorphosis,*
Oxford University Press, Oxford, 1986.

Upper left: Chinese traditional door and knocker in Beijing,China. Middle: Chinese lion on a cloud encircled by bats. Bottom: Some bat fans express their admiration with a bat tattoo. This one shows a lesser long-nosed bat at a saguaro flower. Cut out: Pre-Columbian incense burner with bat motif.

pire bat attacking a cow in Argentina. After his book was published, the bat's association with vampires, night, and terror became entrenched in the modern mind. Beyond the impact of the novel, cinematographic versions of the book, particularly *Nosferatu,* left a bad perception of bats in the collective subconscious of the Western world. This 1920s German horror movie spawned countless vampire movies through modern times, associating vampires, bats, and evil. Beginning in the mid-twentieth century, however, young people in North America drew a more positive association from comic books and movies of "Batman," who uses the cover of night to do good deeds. Clearly, bats have had mixed reviews; in some corners of the globe, they have even been associated with good luck.

In recent centuries, bats have also been an inspiration for a great number of literary works, such as *Don Quixote, The Adventures of Tom Sawyer,* and the poems of Sor Juana Inés de la Cruz, not to mention the new Silverwing series, in which anthropomorphized bats drive the novels. Popular literature often expresses the knowledge or beliefs in the author's world; in many cases, the inclusion of bats functions as a literary device to imprint drama, suspense, fear, or terror. Sometimes bats are treated as characters whose features have nothing in common with the real features of bats.

Eastern cultures such as China and Japan deserve special mention because, for them, bats represent good fortune; they are linked to happiness, and representations of them can be found in religious temples and in many common objects like plates, buttons, handles, and even in clothing and shoes. The Chinese symbol Wu Fu (five bats), frequently used today in various artifacts and ornaments, represents good health, wealth, longevity, good luck, and tranquility. It is said that Japanese artisans designed their paper fans based on the way bats open and close their wings.

Throughout history, open-minded people have shown a positive interest in bats. Leonardo Da Vinci realized bat wings were much more suitable for flight than bird wings, and he used them as inspiration for the design of a flying machine. Years later, with Da Vinci's designs, Clement Ader became the first man to rise from the ground using a steam-powered machine that moved similarly to bat wings. In the twentieth century, the study of bats contributed to the design of radar systems used in submarines, ships, and aircraft. More recently, the components of the saliva of vampire bats have been studied to design a drug, Desmoteplase, that can break up blood clots for the prevention of fatal strokes.

Bats are present in many cultures and have touched the imagination and lives of many people. As we learn more about them, their place in the natural world, and the benefits they provide for us, perceptions of bats will undoubtedly become more positive. With outreach programs in the schools and environmental articles in the media, there is hope that public sympathies around the world will move increasingly toward bat conservation. S

Bat Programs & Organizations

Arizona Game and Fish Department Bat Group
http://www.azgfd.gov/w_c/bat_conservation.shtml

Bat Conservation International
http://www.batcon.org/

EuroBats http://www.eurobats.org/

IUCN Bat Specialist Group http://www.iucnbsg.org/

Latin American Network for Bat Conservation/RELCOM
http://www.relcomlatinoamerica.net/

North American Symposium on Bat Research
http://www.nasbr.org/

Program for Conservation of Mexican Bats/ (PCMM)
http://pcmm.bioconciencia.org.mx/

Western Bat Working Group http://www.wbwg.org/

Year of the Bat http://www.yearofthebat.org/

Photo by Rodrigo Medellin

Photo by Cindy Clapp

Photo by Rodrigo Medellin

Photo by Rodrigo Medellin

Top right: Bat emergence from under the bridge at Campbell and River in Tucson, Arizona. Middle: Chinese dishes with bat motif. Bottom: Contemporary Balinesian bat carving from the village Tegalalang. Cut out: Contemporary Chinese decorative hanging with bat motif.

BATS & BAT HOUSES

Amy Turmelle, Ph.D.
Centers for Disease Control and Prevention

Photo by Karen Krebbs

Photo courtesy University of Florida, Gainesville

Bat houses at the University of Florida in Gainesville, Florida, host tens of thousands of bats and are a local attraction.

Photo by Karen Krebbs

Middle: Bat houses provide roosting space for bats and increase public awareness about the roles bats play.
Right: Bat houses can be installed in a variety of locations, from exterior walls to poles, to trees.

Bats live in a variety of habitats, including natural roosts such as caves, tree cavities, and rock crevices. Some bat species can also tolerate living in man-made or artificial roosts, such as buildings, bridges, culverts, and bat houses. As natural bat habitats have been increasingly destroyed or altered across the landscapes of North America, the number of bats relying on and inhabiting man-made roosts has grown. Bat houses have been constructed in natural parks to increase the number of bat habitats available, and some individuals have constructed bat houses in their yards to provide an alternative to bats roosting in their attic. In some agricultural settings, bat houses have been put up to promote insect control, whereas other bat houses have been erected for exhibit purposes, as a tourist attraction. While all of these uses promote the conservation of these unique animals, bat houses as tourist attractions are particularly important because they increase the public's understanding of bats. But bat houses alone are not enough. It is also important to provide educational outreach.

For example, the University of Florida in Gainesville has a bat house that is home to tens of thousands of Brazilian free-tailed bats *(Tadarida brasiliensis)* and a few hundred southeastern myotis bats *(Myotis austroriparius)*. This bat house has a fence around it to keep humans from disturbing the roost and to keep them away from the fecal material that accumulates underneath. It also has another "buffer" fence to keep observers at a healthy distance while they watch the bats emerge from the roost to forage on insects around campus—a nightly attraction. In the observation area, which is frequented by 20 to 50 persons on many nights, educational signs introduce bats and their benefits to the local ecosystem while also highlighting precautionary statements about avoiding direct contact with the bats, as with any wildlife. The University of Florida bat house is a good model of how to construct an exhibit that operates to protect the public and the bats themselves.

FACTOID

Bats tend to be very long-lived for such small mammals with extremely high metabolisms, many species living 10 to 20 years.

In recent decades, public health recommendations regarding contact with bats and bat habitats have come into greater focus. Most of these guidelines address prevention of rabies, which can be transmitted by bats as by numerous other animals. Recommendations initially published in 1999 by the Advisory Committee on Immunization Practices (ACIP) emphasized the importance of seeking medical advice if you think that you have had contact with a bat. Guidelines published in 2008 by the National Association of State Public Health Veterinarians (NASPHV) recognize that public exhibits of bats can serve an important educational tool and provide a few guidelines to help steer the public away from direct contact with the animals (e.g., handling and touching of bats). These recommendations are meant not to discourage the use of bat houses by the public or by institutions for educational purposes, but merely to encourage a healthy respect in our interactions with bats and other wildlife. Today, it is important to increase public awareness about the role bats play in the overall ecosystem and the need to protect them from threats causing high mortality, such as wind turbines and White-Nose Syndrome. S

Right: ASDM bat specialist Karen Krebbs has been working with bat houses for years.

Building Bat Houses

If you'd like to host bats in your backyard, there are numerous authoritative guides to building or purchasing bat houses. Check the following websites to learn more:

U.S. Fish and Wildlife Service
http://www.fws.gov/Asheville/pdfs/beneficialbats.pdf

National Wildlife Federation
http://www.nwf.org/Get-Outside/Outdoor-Activities/Garden-for-Wildlife/Gardening-Tips/Build-a-Bat-House.aspx?CFID

Bat Conservation International
http://www.batcon.org/pdfs/bathouses/bathousecriteria.pdf

Photo by Merce Tschapka

BAT CONSERVATION:

Priorities and Initiatives in the Sonoran Desert Region

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Bats have been on our planet for more than 50 million years, long before humans walked the Earth. Today, however, many species of bats are threatened with extinction. Like other wildlife, bats suffer from habitat degradation and destruction. They are also threatened where they live, forage, and travel—from deliberate acts to diminishing resources. Important predators of night-flying insects as well as pollinators and seed-dispersers of iconic Sonoran Desert plants, bats need our help and protection now more than ever.

Bat needs are analogous to basic human needs, which include year-round safe housing, clean water, and sufficient food. They also require safe passage from their roosting to their foraging sites. Unfortunately, many species of bats known from the Sonoran Desert, like bats elsewhere, face numerous negative impacts including:

- loss of roosting habitat
- reduced water quality and/or availability
- declining food resources
- threats to daily and/or seasonal travel

A HOME OF THEIR OWN—
It's Not Just about Caves

When we think of bats, we often think of caves. Many of us have seen spectacular images of large emergence flights from places like Carlsbad Caverns, but there are many species of bats that rarely, if ever, enter caves. Big free-tailed bats roost in cliff crevices high in mountain canyons. Their wings are so long and narrow that they must drop from great heights and spread their wings before they can gain flight.

Other species live in trees, either in natural cavities or those excavated by other animals. Big-eared bats can live in the cave-like basal hollows that form in large old-growth trees. Big brown bats have been known to roost in saguaro boots. Still others hang right out among the leaves of trees. Yellow bats roost in the dead fronds of wild palms or in dried skirts of soaptree yuccas. Pallid bats and Mexican long-tongued bats will use rock crevices or small erosional caves hollowed out by wind or water along washes.

As humans have altered cave habitats and logged forests, many bats have lost their natural roosts. These bats have learned to use man-made structures for roosts. Some of our most familiar bats, like little brown and Mexican free-tailed bats, have adapted to live in attics, barns, old wooden buildings, bridges, and abandoned mines—structures that approximate the conditions bats found in their traditional forest and cave habitats.

Wherever bats roost, they have critical thermodynamic needs. Maternity colonies of most species must be warm and in habitats with rich food resources so young can grow and develop rapidly. Hibernation sites on the other hand, which some bat species of the Sonoran Desert Region use to survive the winter, must be cold but with stable temperatures that don't drop below freezing. This allows bats to reduce their metabolisms and survive an entire winter without food, using just 5 to10 grams of stored fat (roughly the weight of 5 to10 plain M&M candies).

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Opposite page: Pallas's long-tongued bat drinking nectar from the flower of a morning glory tree. Top: Western yellow bat in palm frond. Bottom left: Hoary bat in oak tree. Bottom right: Pallid bats seek their prey on tree trunks, vegetation, or rocky substrates.

Top: A Townsend's big-eared bat catching a drink of water. Bottom left: Mexican long-tongued bat drinking from hummingbird feeder. Bottom right: This stock tank/water-for-wildlife tank in the Chiricahua Mountains was installed through a joint effort by BCI, the USDA Forest Service, Bureau of Land Management, and the Arizona Game and Fish Department. Thirteen of the area's 21 bat species have been caught over the tank since it was rehabilitated with an "escape ramp." The ramp can be easily be constructed by bending a small sheet of expanded metal and affixing it to the lip of the tank, leaving no gaps that can trap bats (or other wildlife) and providing a "grippy" surface to climb.

Disturbance in caves and mines can be deadly. Any disturbance of bats during the winter costs each bat its precious fat reserves. Disturbance of maternity colonies in the summer can be just as fatal. Mothers can be startled and fly suddenly from the roost, bumping flightless young who fall to the cave floor and perish. Illegal border activity also contributes to roost disturbance, because border crossers often use caves and mines for shelter.

LIQUID GOLD—
Bats on the Western Water Front

A growing threat to our desert bats is a decline of water resources stemming from myriad factors, including declining water tables due to drought and over-grazing (which depletes the grasses that help recharge groundwater), the damming of rivers, and large-scale irrigation projects.

Unlike most terrestrial wildlife, bats drink on the wing. They swoop low and slow over pooled water to grab a drink. But bat species differ in whether or how they access water resources of various sizes, according to their flying abilities. One of the most commonly used water sources for bats in the Sonoran Desert are the numerous stock tanks on public and private rangeland. A recent Bat Conservation International (BCI) study evaluated over 500 livestock waters in the Southwest and found that more than 50 percent had obstructions that would render them useless to bats attempting to drink. More than 90 percent had no proper wildlife escape ramps, causing bats and other wildlife to drown. These losses are especially unfortunate because they are easily avoidable. Simply keeping water levels full, keeping water surfaces free from obstructions, and installing escape ramps would benefit many bat species and other wildlife in the Southwest. And redesigning livestock and wildlife water tanks would significantly improve bat survival. Urban and suburban residents in the Sonoran Desert can help, too. Conserving water by landscaping with native plants, harvesting rainwater, and using water-friendly technology helps the entire desert ecosystem and all plants and wildlife within it.

> *Bats have such high energy demands that if a nursing mother cannot locate food for two days she will starve.*
>
> FACTOID

WINDS OF CHANGE—
Dangers on the Landscape

Bats' needs vary by season. Some species hibernate to survive the winter, when food resources are insufficient. Other species migrate south to warmer climates where food is available. Nectar-feeding lesser long-nosed bats have been documented making annual migrations of more than 1,000 miles to travel from summer maternity sites in southwestern Arizona and northwestern Mexico to winter sites in western and central Mexico. Migration distances vary by species.

On their migration routes bats need a reliable supply of suitable roosts, food, and water. But those resources are increasingly threatened. Pesticide use decreases foraging opportunities for insect-eating bats, and land conversion that reduces populations of columnar cacti and agave can leave nectar-feeding bats with little to eat. One of the biggest threats to our migratory nectar bats is agave cultivation for tequila production, which leads to food gaps along large stretches of their migratory corridor. Because the agave used to produce tequila is typically prevented from flowering, bats reaching these areas are unable to find food. Fortunately, BCI and others have worked with growers to plant "hedgerows" of native agave that will be allowed to flower. This keeps the nectar corridor intact and provides migratory bats with essential fuel to reach their destinations.

Another danger is the proliferation of electricity-generating wind turbines. Although they are considered a source of "green energy," there is an ecological cost associated with wind turbines, which have been found to cause significant mortality in migrating bird and bat

Top left: Wind turbines have caused significant mortality in migrating bird and bat populations. Top right: Cow walking through an agave field grown for tequila, where the agave plants are prevented from blooming and thus are useless as food for bats. Bottom: Ghost-faced bats roost in large numbers in caves.


Photo by Karen Krabbs


Photo by Rogelio Manrique


Photo by Rodrigo Medellin

Top left: Man made bat roost attached to a palm tree. It appears that bat houses on trees, however, are not as successful as those on walls. Top right: Lesser long-nosed bat with pollen on its head. Bottom: Bats emerging in large numbers from a cave in Mexico.

populations. Thousands of bats are killed by turbines annually. Tree-dwelling species may be attracted to turbines because they resemble large tree snags that are attractive roost sites. Beyond direct collision with blades (which have tip-speeds up to 200 mph), researchers have found that a change in air pressure near the blades causes fatal internal bleeding in the small-bodied bats. The placement of wind farms, avoiding areas that are important to bats and other wildlife, will be critical in reducing deaths, as will curtailing turbine use during peak migration periods. Luckily, many wind energy corporations are interested in working with conservationists to solve this emerging problem. Bat Conservation International has a strong program to help and has provided guidelines for mitigating the effects of wind turbines. In Arizona, the Game and Fish Department also has "wind-wildlife guidelines" to help developers examine potential impacts of their projects on wildlife and to guide essential monitoring studies that should occur before and after construction.

WHAT CAN YOU DO
and Why Should You Care?

Because bat success depends on many factors affecting summer and winter roosts, water resources, food availability, and safe movements, anyone can help to increase the survival of bat populations by simply improving the availability of just one of those resources. As individuals or through community action and conservation organizations, we can maintain reliable water sources. We can also create man-made roosts such as bat houses as a stop-gap until natural roosting resources can be restored. Much can be accomplished simply by encouraging and sharing an appreciation for bats and their critical contributions to the Sonoran ecosystems. Already, outreach programs are changing long-held prejudices that have threatened bats in the past.

In the Sonoran Desert Region several programs engage the public and educate professionals. A citizen-science project in southern Arizona (conducted by the Arizona Game and Fish Department [AZGFD], the U.S. Fish and Wildlife Service [USFWS], the town of Marana, BCI, the University of Arizona, and others) asks residents to collect data on the visitation at hummingbird feeders by nectar feeding bats in the late summer within the range of the lesser long-nosed bat. We are learning when the bats arrive and leave each year and whether and how the bats supplement their natural diet by visiting hummingbird feeders. The more we know, and the better we understand bats, the better we can accommodate their needs along with ours.

Another conservation initiative for bats in the Sonoran Desert Region is a joint education and training program begun in 2008 by the Mexican nonprofit organization Naturalia and USFWS. Each year, two or more workshops or training field trips for university students and young wildlife biologists are held in Sonora or adjacent Mexican states on research, management, and conservation of bats. The goal of these workshops is to build local capacity for bat conservation and to train biologists to educate the general public on the important role bats play in the Sonoran Desert ecosystem. Since 2008 new partners have joined this effort, including BCI, AZGFD, the National Autonomous University of Mexico (UNAM), and the Arizona-Sonora Desert Museum.

FACTOID

Bats are not related to mice, but shrews and moles and bats evolved from a common ancestor living 60 or 70 million years ago.

We've made great strides in the past ten years for at-risk bat populations, but the emerging threats of wind power, climate change, and increasing human populations in the Sonoran Desert continue to challenge us. Please help make it possible for these fascinating and important animals to survive and contribute to Earth's ecosystems for another million years. It is our turn to pay tribute to what these bats do for the ecosystem and for our society. S


Photo by Brock Fenton


Photo © John Ohmer/BCM


Photo © BCI


Photo by Winifred Frick

Top left: The tri-colored bat *(Perimyotis subflavus)*, an insectivorous bat common in the East from Canada to Mexico and Central America, is thought to roost in foliage or tree cavities. Top right: Janet Tyburec of BCI with bat workshop participants near Portal, Arizona. Janet is demonstrating how to safely remove bats from mist nets and handle them properly so they can be identified, measured, and recorded. Bottom left: Pallid bats hanging from rafters in a shed. Bottom right: Lesser long-nosed bats are powerful fliers, migrating over 1,000 miles each year.

Photo by Alan C. Hicks

Photo by Alan C. Hicks

Top: Northern long-eared bat *(Myotis septentrionalis)* infected with White-Nose Syndrome. Characteristic white fungal growth is visible on forearm, ears, and nose areas. Bottom: Pile of bat bones in bat guano, demonstrating the severity of mortality associated with WNS, at Aeolus Cave in Vermont. Cut out: A cluster of little brown bats in hybernation in Aeolus Cave, Vermont.

WHITE-NOSE SYDROME: *A Threat to Hibernating Bats*

Photo by Marianne Moore

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In the winter of 2007 while surveying caves and mines where bats hibernate, bat biologists near Albany, New York, saw something they had never seen before—piles of dead bats on the cave floors and an unusual white growth on the faces and wings of hibernating bats. Bats had also been seen flying around in mid-winter. These were the first indications of what is now known as White-Nose Syndrome (WNS), an infectious disease that is causing the most severe population declines of bats in North American history.

WNS is associated with a recently described fungal pathogen *(Geomyces destructans),* which grows best in the cold temperatures preferred by bats during hibernation (39º–59º F). This fungus causes a skin infection that invades the dermis and epidermis, filling sweat glands and hair follicles with fungal growth. Why this fungal infection kills the bats is still being researched, but it appears that infected bats wake too frequently during their winter hibernation and starve to death before spring. Experts have estimated that over one million bats died in just the first couple of years of this disease epidemic.

The pathogen has spread rapidly across eastern North America since its initial discovery near Albany. By spring 2010, *G. destructans* had been detected throughout the northeastern United States into Tennessee, as far west as Oklahoma, and into Quebec and Ontario in Canada. Early reports in 2011 indicate its march into Indiana and North Carolina. All six species of hibernating bats in the Northeast—little brown myotis *(Myotis lucifugus),* northern long-eared myotis *(M. septentrionalis),* eastern small-footed myotis *(M. leibii),* Indiana bat *(M. sodalis),* tri-colored bat *(Perimyotis subflavus),* and big brown bat *(Eptesicus fuscus)*—have shown signs of infection, although some species appear to have higher mortality rates from the disease than others. Three additional species—gray myotis *(M. grisescens),* southeastern myotis *(M. austroriparius),* and cave myotis *(M. velifer)*—have been detected with the fungus, but have yet to show clinical signs of the disease. The little brown myotis, once the most common species in the Northeast, has sustained the highest rates of mortality and may soon face extirpation in that region if mortality and spread continue unabated.

There is much concern and speculation about the potential impact of WNS on bats in the western United States and into Mexico. It seems only a matter of time before the fungus spreads throughout the continent. Winter ecology of bats in the West is poorly understood, and researchers know less about the size and locations of hibernating colonies of bats west of the Rockies than in eastern North America. In general, hibernating colonies in the West seem to be smaller and more spread out than in the East. If densities of bats at hibernacula matter for disease transmission, these populations could be less threatened. Areas with milder winters may also allow bats to forage during mild winter weather. The high diversity of bats in the Sonoran Desert Region makes it an area of particular interest and concern for how this disease may spread into new environs. Early monitoring programs to detect the arrival of WNS and assess population impacts will be critical to determine the degree of its threat in the Sonoran Desert Region. It is premature to predict the impact that WNS may have there, but in the Northeast it remains the greatest threat to bat conservation in our time.

Many agencies, including the National Park Service and U.S. Forest Service, have begun to restrict cave tourism and caving activities as precautionary measures in preventing the potential spread of *G. destructans* by humans. Bats are likely the primary agents of dispersal among caves, but humans may have played a role in the large geographic leaps in the distribution of the fungus. These agencies recommend that people visiting caves not wear clothes or boots that have been worn in a WNS-infected area, and that cavers and bat researchers adhere to the decontamination protocols available on the U.S. Fish and Wildlife website (http://www.fws.gov/whitenosesyndrome/). S

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BATS & RABIES

Rabies is one of the oldest diseases known to man. Around 2,300 B.C. scribes in Eshnunna, Babylon, recorded fines to dog owners for deaths caused by the bite of mad dogs. While rabies in domestic pets has been largely curbed in many countries, rabies persists among wild populations of carnivores, such as foxes, coyotes, raccoons, skunks, and bats (including those bats that have diets of insects, fruits, or blood). In the United States, rabies occurs in all states except Hawaii. All mammals (including ourselves) are susceptible to the disease, which is typically transmitted by the bite of an infected animal. Other routes of transmission are possible (e.g., oral ingestion of infected tissues or organ transplantation from an infected donor), but all other routes are insignificant when compared to transmission by bite.

There is general misconception about rabies in bats, including an incorrect belief that the incidence of infection is uniformly high among populations of bats. In fact, scientists know from extensive surveillance of bat populations over the last half-century that the typical incidence of infection in natural populations is less than one percent. That is, only a *very* small fraction of these flying mammals are capable of transmitting the disease (i.e., are rabid). In the United States, among bats that come into contact with the public and are submitted to state public health departments for rabies testing, the proportion infected is slightly higher, at four percent to six percent of animals tested—still a small fraction, given that the circumstances of human contact may warrant further investigation. (However, this percentage can vary widely among different species of bats.)

Due to the serious nature of this disease, of course, it is always best to seek medical advice if you have been exposed to a suspect animal. On average, two to four humans die of rabies each year in the United States (total, not necessarily from bats). These deaths represent individuals that did not recognize their exposure or did not seek treatment following exposure. Seeking timely medical advice and treatment is critical. In the United States, an estimated 35,000 people are treated with post-exposure prophylaxis each year. With timely treatment, the disease is completely preventable. Treatment includes thorough cleansing of the wound and surrounding area with soap and water, as well as timely vaccination, including a series of four injections of vaccine and separate injections of anti-rabies antibodies to help fight off early stages of viral replication.

In summary, although rabies is a very serious disease, generally only a small fraction of wild carnivores and bats transmit the virus. We also know that bats perform a variety of invaluable ecosystem services, including insect control, pollination of plants, and seed dispersal that can lead to forest regeneration. Therefore, it is incumbent upon us to take precautions to observe and appreciate wildlife in a safe manner, avoiding direct contact and confrontations. Because rabies can lead to unnatural behavior in an infected animal, it is important to *stay alert and be wary of wild creatures that seem to be disoriented, paralyzed, or indiscriminately aggressive.* By taking a few responsible precautions, we can help to prevent exposures to this ancient disease. S

Cut out above: A figurine from the Neo-Babylonian Dynasty (700-500 B.C.) representing a rabid dog. This terracotta animal is in the Mesopotamian collection of The British Museum. Used with permission.

Pallas's
long-tongued bat

Photo by Brock Fenton

THE FUTURE:
Bat Research & Conservation

Gerald Gunnawa Carter, Department of Biology, University of Maryland

LOOKING FORWARD

What can we say about the next 20 years of bat conservation and research? Our predictions about the future of science tend to look humorously inaccurate in retrospect. Modern science has produced the internet, genetically engineered food, and human genome sequencing, but not much in the way of interstellar space travel. Our ineptitude in forecasting advances in science and technology is largely due to the fact that scientific research is so opportunistic. Its direction is driven not merely by what progress we want to see, but often by opportunities opened by unforeseen advances in technology. New cohorts of tech-savvy young scientists are continually exploring topics never before possible. In the science of bat research and conservation, new technologies are paving the way to answer some of our biggest questions. By learning more about bats, we can better understand and address threats to their survival and to the roles they play in healthy ecosystems. By looking at the intersection of the most pressing questions and the fastest-growing technologies, we can identify a couple of research avenues that promise great returns.

In the past, biologists studied bat movements by banding many bats and hoping that someone somewhere would catch those same bats. As you can imagine, it wasn't very efficient. Today, researchers are investigating the patterns of bat movements through a variety of more sophisticated methods. Researchers routinely attach tiny transmitters to bats to track where they fly and roost; and even their temperatures. These transmitters emit pulses of radio waves that allow researchers to triangulate and track their positions, and new models of tracking devices are getting smaller and more advanced. The newest transmitters can communicate with satellites to reconstruct flight paths of long-range migrations, but these are still too large for most bats.

Photo by Gerald Carter

Photo courtesy Winifred Frick

Gerald Carter tracking bat movements by telemetry; Winifred Frick releasing a lesser long-nosed bat on Isla Carmen in the Sea of Cortez under a full moon. Right : Big-eared wooly bat *(Chrotopterus auritus)*, one of the largest predatory bats in the neotropics.

In an emerging field called "aeroecology," researchers are using advanced weather radar systems to track movements of both bats and their insect prey without the need to catch them. Researchers are now using data from Doppler radar systems to reconstruct three-dimensional models of millions of Mexican free-tailed bats emerging from caves in Texas, climbing high into the night sky, and consuming millions of migrating moths.

In light of the huge threat posed by wind farms, one of the most pressing questions in bat conservation is clear. Where and when do bats migrate? In the years to come, our knowledge of bat migration will undoubtedly take leaps forward, propelled by continuing advances in tracking technologies.

Bat movements can also be assessed indirectly in some rather ingenious ways. When animals eat, they acquire the atoms from their local environment into their bodies. Since the ratios of stable hydrogen isotopes change with latitude, the stable hydrogen isotope ratios of bat fur can reveal where bats have been traveling and eating. Similarly, since desert plants use different versions of photosynthesis (CAM photosynthesis and C3 carbon fixation), they can produce distinct carbon isotope ratios in their tissues. Researchers have used stable carbon isotope analysis to show that endangered lesser long-nosed bats

Photo by Angelina Menchaca

The sight of large numbers of bats flying in the twilight is always spectacular.

Photo © BCI

Little yellow-shouldered bats are important seed dispersers in tropical forests.

Photo by Marco Tschapka

rely heavily on agave plants on their migration south and on dense stands of columnar cacti on their way back north.

Stable isotopes are not the only kind of invisible clue available to researchers. Using tissue samples of lesser long-nosed bats caught in only 13 locations, researchers have also described genetic divergence between populations and migration routes by analyzing variation in DNA. The use of such genetic information in ecology studies has exploded in recent years, and what we are seeing is likely only the tip of the iceberg.

CLUES FROM GENES & GENOMES

The realization that huge amounts of ecological information can be obtained from DNA has led to the exploding field of molecular ecology, and in coming decades molecular tools will be increasingly important for bat ecologists. In fact, the fastest growing scientific technology today is DNA sequencing. Since the information for building an organism is written in the DNA code, sequencing fragments of DNA, or even the entire genome of an individual, has the potential to reveal all the biological information that makes an individual or species unique. Tracing changes in the genomes from one population of animals to another allows us to map exactly how they are related to each other on the family tree of all life. As the evolutionary history of bats becomes increasingly clear through molecular techniques, we will have a better understanding of how, why, and where bats evolved and how they are related to all other living things. Studies of gene flow and population genetics can help us identify the populations for which conservation is most critical.

Molecular techniques can also answer more basic ecological questions. For instance, we can use DNA to study kinship, family dynamics, and social lives of bats, or we can sequence the prey DNA in bat guano to see what bats eat. Sequencing the DNA of the pathogenic fungus *Geomyces destructans,* which causes White-Nose Syndrome, may help us understand where the fungus came from and what makes it so destructive to North American bat populations. The information in DNA is profoundly vast and will only be fully realized by future generations.

A genome is like a code for making an organism, but the information remains largely encrypted. Although we know the information is there, we are still not sure which parts of genomes are meaningful. But comparisons can give us information. By comparing genes and genomes, the evolution of similarities and differences among and within living species can be identified. In the future, we might be able to "read" genomes in the same way we read the blueprint for an invention. We might be able to predict much about the biology, ecology, even behavior of an unfamiliar organism simply by sequencing the DNA in a speck of tissue. This is the lofty goal of bioinformatics, possibly the fastest growing field of science. Bats have evolved into more than 1,200 species, and possess an extraordinary amount of genetic diversity even within a single species. The next few decades will allow us to explore how and why bats became so successful and speciose.

Whither the NATURAL HISTORY OF BATS?

Does this era of modern molecular biology spell doom for organismal biology? Today, natural history, the description of nature, is more likely to grace the pages of popular magazines than of leading scientific journals. Natural history developed into the science of organismal biology, including ornithology, ichthyology, mammalogy, and others. Compared to modern molecular genetics, these taxon-specific fields often seem to be in academic decline, receiving less science funding and less academic attention. Modern biologists have been increasingly turning their attention away from particular species toward genes and ecosystems. As one of my colleagues once put it, "DNA is DNA. I don't always know what the animals even look like." At the same time, the modern conservation movement has also been trending toward a focus on conserving ecosystems, rather than on protecting single species one at a time. This holistic approach is efficient because habitat destruction and anthropogenic changes at the ecosystem level are problems that threaten multiple species. From this perspective, one might wonder why we should even focus time and energy specifically on bats. It may seem that by simply protecting habitat, we will be protecting bats alongside other wildlife, and we might not need to know detailed ecological information about the lives of bats.

But this view is naïve. Knowing the natural history of bats is as indispensable as ever to their conservation. The problems of wind turbines and White-Nose Syndrome clearly make this point, because these threats endanger bats specifically. In order to confront such threats, we must possess intimate knowledge about behavior, ecology, and physiology unique to bats. And the bulk of this knowledge is simply lacking. When bat biologists first realized the gravity of the threat that wind turbines posed to migratory bats, we were all but embarrassed to admit to ourselves just how little we knew about bat migration or the

Photo by Marco Tschapka

Lesser long-nosed bats provide essential linkages to ensure sexual reproduction among many columnar cacti in the Sonoran Desert.

Photo © BCI

Lesser long-nosed bats also disperse the seeds of many columnar cacti.

Photo by Paul Berquist/ASDM digital library

The big brown bat consumes significant numbers of crop and forest pests.

Photoby Winifred Frick

Recent research indicates that some Baja populations of insectivorous pallid bats also take advantage of floral nectar.

population sizes of migratory bats. Where did different bats migrate? How many were there? How far did they go? What paths did they take? These and other basic questions must be addressed by researchers in the coming years. Similarly, white-nose syndrome was discovered as early as it was thanks to the work of bat biologists who actively monitored caves and mines where bats hibernate. There's simply no replacement for careful observations of the natural world.

One obvious lesson we can take from these recent threats to bat conservation is that organismal biology and species-specific natural history are *absolutely essential* for conservation. Only a few years ago, I would have written that the future of bat conservation in North America lies in protection of habitats and ecosystems. No one expected the White-Nose Syndrome population crash or the mortality effect of wind turbines. Few scientists or conservationists expected that detailed information about the immune systems or migration patterns of particular bat species would become so immediately and extraordinarily crucial to their conservation.

General conservation and ecology is not enough. We need to know more about the natural history of most of the North American bats. To save bats, we need people who call themselves bat biologists. Not all the most important questions can be solved quickly with the latest technologies; sometimes solutions are best acquired through years of rigorous fieldwork. Gathering important ecological data or observing natural behaviors often requires long days over continuous months in the field. But the experience is rewarding, and the results can be illuminating.

Ecological fieldwork is still crucial for determining what role bats play in a healthy ecosystem and how important bats are for producing the essential resources people derive from natural communities. For example, experiments on bat pollination have shown that bats are generally more effective pollinators of plants per visit than bees or birds. In fact, plants once pollinated by birds have more often evolved to become bat-pollinated than vice versa. However, in many areas, desert plants adapted for bat pollination now rely increasingly on suboptimal insect or bird pollinators simply because the bats have become too scarce. Other plants that are tightly coevolved with bats will not be able to adapt so quickly to the local loss of bat populations. The fate of bat pollinators and many of their desert plant allies are intertwined: a threat to one poses a threat to the other. Other recent ecological studies have shown the importance of bats in reducing insect pests (up to 84 percent in Mexican coffee plantations). In 2011, a report in the journal *Science* suggested that the insect-control services of bats were worth roughly $23 billion each year to agriculture. In most cases, the ecological importance of bats is vaguely known, but not well documented. Further ecological studies documenting the importance of bats will be vital to their conservation.

Given their huge diversity, great abundance, and wide-ranging distribution, as well as the critical roles they play in ecosystems and in our own well-being, bats will no doubt continue to be the focus of many scientists around the world. This particular field continues to grow and attract some of our brightest young minds. Many more questions remain than can be answered with the current workforce. Luckily, searching for the answers is exciting, and finding them holds promise for a better world for humans and for bats. S

Suggested Readings on Bats

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Photo by Rodrigo Medellin

The National Autonomous University of Mexico carries out research conservation in many areas of the country, including cave surveys. Here, a group of students under the direction of Dr. Medellin (lower left) monitor a Mexican free-tailed bat colony in Chiapas, Mexico.

Photo by Marco Tschapka

The flight of a Baja California fish-eating bat is observed in a flight cage.

ARIZONA SONORA DESERT MUSEUM

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California leaf-nosed bat

Photo by Angelica Menchaca

Photo by Winifred Frick

Townsends' big-eared bat

Photo by Winifred Frick

Hoary bat

Photo by Rodrigo Medellin

Common vampire bat

Photo by Rodrigo Medellin

Ghost-faced bat

Photo by Rodrigo Medellin

Mexican free-tailed bat

Photo by Rodrigo Medellin

Baja California fish-eating bat

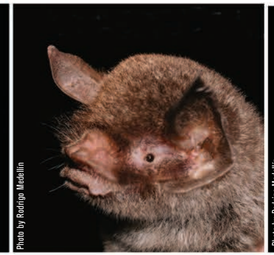

Photo by Rodrigo Medellin

Parnell's mustached bat

Photo by Rodrigo Medellin

Wagner's mustached bat

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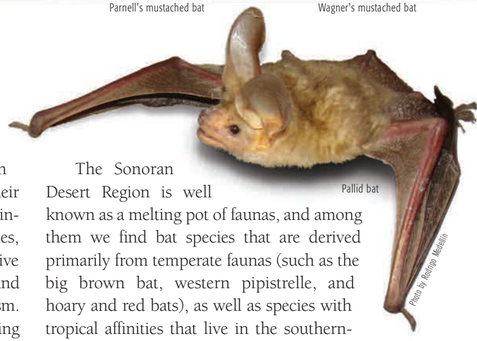
BAT DIVERSITY *in the* SONORAN DESERT

The Sonoran Desert Region, from southeastern California and Arizona to Baja California and Sonora, contains at least 48 species of bats—more than the total number of bat species in the entire United States. Almost all our bat species live in desert habitats, but some are exclusive inhabitants of the tropical areas of southern Sonora, and a few others typically inhabit boreal forests such as those on the sky islands. From south to north in the Sonoran Desert the number of bat species declines—with the greatest number in southern Sonora, the smallest in Arizona. From east to west, the number only changes slightly, with some species replacing others as we move into Baja California. These bats come in various shapes, sizes, and behaviors, with lifestyles that reflect the rich biological diversity of the region itself.

There are bats that fly very high above the vegetation and others that fly close to the ground. Some bats use rivers, streams, and washes as flyways, while others seek wide open spaces to search for their prey. There are bats with humongous ears, others with tiny ears. Some bats have a very long snout, and others a rostrum so short they look almost like monkeys. Some of our Sonoran Desert bats, like the mastiff bat or the Mexican free-tailed bat, have long, narrow wings that help them fly in the open at high speeds with relatively straight trajectories. Others, such as the little brown bat and the western pipistrelle, have shorter wings, which provide the amazing dexterity they demonstrate chasing moths and other prey in mid-air, following each swift twist and sudden turn. Still others, such as the pallid bat or the California leaf-nosed bat, have short, broad, powerful, and strong wings. This wing structure is ideal for the very slow flight they need to survey the ground or vegetation for prey. After landing on their prey and delivering several killing bites, they are able take off again carrying prey of up to 30 percent of their own weight.

In the Sonoran Desert a small group of species stay year-round, but most only take advantage of the plentiful resources the desert offers during the summer, migrating from central or southern Mexico to Sonora and Arizona. Although not yet verified, it is thought that some hoary bats and red bats can migrate annually all the way from Canada to Mexico and back. Some of the year-round Sonoran Desert residents hibernate in winter, lowering their metabolism to one heartbeat per minute and maintaining a temperature of 35º to 40º F. Other species, such as the California leaf-nosed bat, remain active throughout the winter where climates are mild and insects are available to fuel their high metabolism. These bats depend on "hot caves" and mines during colder periods. Some migrating bats, like lesser long-nosed bats, also make use of hot caves, which have chambers with elevated ceilings that trap the heat and maintain the temperature range bats need for reproduction. Newborn babies of these species also gather together in large numbers to keep warm.



Pallid bat

Photo by Rodrigo Medellin

The Sonoran Desert Region is well known as a melting pot of faunas, and among them we find bat species that are derived primarily from temperate faunas (such as the big brown bat, western pipistrelle, and hoary and red bats), as well as species with tropical affinities that live in the southernmost skirts of the region (such as the hairy fig-eating bat, funnel-eared bat, Gray sac-winged bat, ghost-faced bat, and the mustached bat). Several species have evolved as unique endemics to the Sonoran Desert, including the fish-eating bat of the Sea of Cortez and the California leaf-nosed bat.

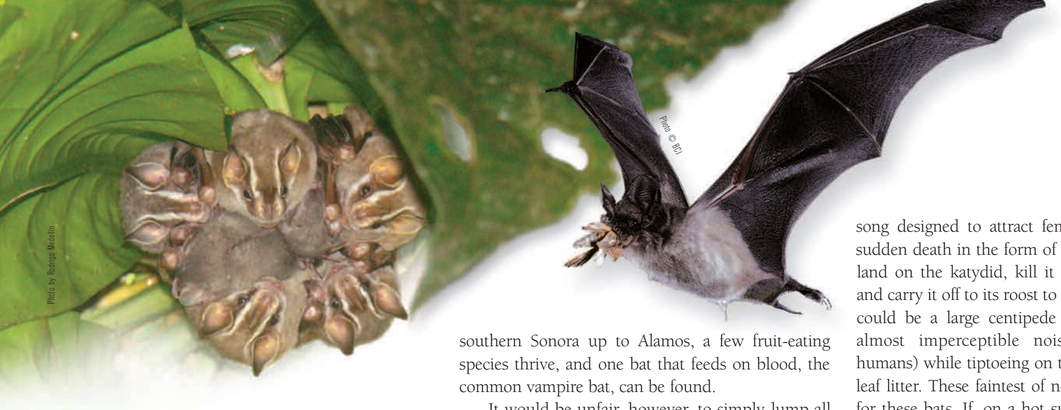


Photo by Rodrigo Medellín

Photo © BIO

Top: Bats have adapted to many habitats. These cute little bats from Costa Rica, Watson's fruit-eating bats *(Artibeus watsoni)*, make tents out of large tropical leaves. Above: ASDM docents host a regular bat-emergence event at the bridge near Campbell and River Roads in Tucson. Cut out: Mexican free-tailed bats feed on moths and other soft-bodied insects.

TIME TO EAT:
Their Special Diets and What They Mean

The Sonoran Desert Region is home to many insectivorous bats, as well as nectar feeders and the unique fish-eating bat. In the more tropical habitats from southern Sonora up to Alamos, a few fruit-eating species thrive, and one bat that feeds on blood, the common vampire bat, can be found.

It would be unfair, however, to simply lump all the bats that feed on insects and other arthropods in one category. Some species, such as the Mexican free-tailed bat, specialize in feeding on moths, flies, and other soft-bodied insects, taking them on the wing (while both are flying). One of the most visible bats in our region, the Mexican free-tailed bat roosts in large to huge numbers; one cave near Carbó, Sonora, contains over five million bats, and the bridge near Campbell and River Road in Tucson, Arizona, contains tens of thousands. Free-tails are "swarm feeders" that fly through large groups of insects. One million of these bats destroy *ten tons* of insects every night! This in itself is such a remarkable service to ecosystems and to humans that it is hard to imagine a world with no insect-eating bats. Other species, like the big brown bat, feed on beetles and other hard-bodied insects on the fly.

But there are others, such as the pallid bat and the California leaf-nosed bat, that specialize in capturing arthropod prey on the ground or vegetative surface, cueing in on sounds produced by the prey. A katydid grasshopper happily singing its summer song, a love song designed to attract females, is also attracting sudden death in the form of a powerful bat that can land on the katydid, kill it with a couple of bites, and carry it off to its roost to savor a tasty meal. Or it could be a large centipede or a scorpion making almost imperceptible noises (certainly for us humans) while tiptoeing on the sand or under some leaf litter. These faintest of noises herald "mealtime" for these bats. If, on a hot summer night, you have occasion to observe life under a big light, you will see that the light attracts lots of flying insects that then fall to the ground, in turn attracting centipedes, scorpions, and large spiders. If you watch, you will undoubtedly see bats hawking the flying insects overhead. Closer to the ground, bats that eat terrestrial arthropods will pass through, selecting their next unsuspecting prey as if at a buffet dinner.

Other bat species feed primarily on nectar and pollen from several plant species— from columnar cacti like saguaro, cardon, and organ pipe, to agaves and morning glory trees. Most of these plant-loving bats are migratory. You may have noticed them visiting your hummingbird feeders, primarily in August (although some Mexican long-tongued bats remain in southern Arizona in the winter and also rely on hummingbird feeders during the colder months). These fascinating animals have an intimate connection with the desert plants: over many centuries the vast majority of the pollination of these columnar cacti and agaves has been carried out by bats. In other words, our familiar landscape with its striking, enormous cacti, is the result of millions of years of connections between bats and plants.

The great majority of the nectar bats in our region are females bearing or suckling young, since the males remain behind in western Mexico. These females carry out migrations of more than a thousand miles as a bat flies, from west-central Mexico, around the coast of Jalisco near Puerto Vallarta and farther south, all the way up to Sonora and Arizona. It is hard to believe that this demanding trip is fueled only by nectar and pollen! And in their long migration, they provide important benefits to humans. Their pollination of agave is essential not only to the ecosystems, but to many humans too. Agaves are the source of many useful products—from natural ropes and string to syrups, to the larvae of a moth used as food in central Mexico, to tequila, mescal, and other beverages. Many millions of dollars are derived from the relationship between bats and agaves; in fact, tequila sales represent almost one billion dollars annually.

A few bat species in the southern end of the region feed on the fruits of tropical trees such as the native fig tree, dispersing its seeds and ensuring that the next generation of trees will be part of the tropical dry forest. One species endemic to the Sea of Cortez, the fish-eating bat, spends its entire lifetime on islands of the Gulf. It forages over the waves of the sea, never drinking fresh water. This remarkable bat is large,


Photo © BIO

Lesser long-nosed bats pollinate an agave. Right: Mexican free-tailed bats form tight clusters on the ceiling of a cave. Cut out: Shot of tequila with limes. Tequila is made from agave plants.

among the largest bats in our region, with a wingspan of about 17 inches and weighing almost an ounce. Its feet have elongated, flattened, recurved sharp claws, with which they hook fish and aquatic invertebrates from the ocean surface.

SURVIVAL STRATEGIES
Tailored to Place

Along with their great diversity in shapes and diets, bats have evolved wide-ranging survival strategies. All bat species in the Sonoran Desert use the sophisticated echolocation system for which they are renowned. Some rely on it to locate tiny insects in mid-air, others to navigate in and out of their roosts or to find their way through forest understory. Interestingly, preliminary evidence hints that even nectar bats, which have not generally been known for their use of echolocation, use it to find flowers. Some bats have color vision, some black-and-white vision. Where and how they roost depends on where they evolved and the resources available to them—from cavities in trees and cacti to rock crevices, to bark, leaves, and manmade structures. Most bats have two types of roosts, one in which to rest during the day and the other in which to eat and digest food during the night's foraging activity. Bats hanging on your front porch wall during the night will usually be absent during the day.


Photo by Rodrigo Medellín

NOT JUST "A BAT"

With this brief overview, we hope to have passed on to you our enthusiasm and appreciation for the extraordinary diversity of bats in the Sonoran Desert Region, not only in the number of species, but also in their morphology, food habits, behaviors, and above all, the remarkable services they provide to ecosystems and to us. Next time you are out enjoying a splendid desert evening and see a bat chasing a moth, or see one visiting your hummingbird feeder, you might say quietly, "Thank you, friend." S

BATS OF THE SONORAN DESERT REGION

In the order Chiroptera, worldwide, there are approximately 1,200 known species of bats. In the Sonoran Desert Region, there are at least 48. Here, we list bat species found in Sonora, Baja California, the islands of the Gulf, and the stateside portion of the Sonoran Desert.

Photo series by Marco Tschapka

Above series of photos: Pallas's long-tongued bat drinking nectar from a morning glory tree.

Common Name	Species	Distribution	Diet
Free-tailed Bat Family *(Molossidae)*			
big free-tailed bat	*Nyctinomops macrotis*	C & N Mexico & S US	I
greater mastiff bat	*Eumops perotis*	C & N Mexico & S US	I
Peale's free-tailed bat	*Nyctinomops aurispinosus*	Tropical	I
pocketed free-tailed bat	*Nyctinomops femorosaccus*	C & N Mexico & S US	I
Underwood's mastiff bat	*Eumops underwoodi*	W Mexico & SW US	I
Funnel-eared Bat Family *(Natalidae)*			
(No common name)	*Natalus lanatus*	Endemic to W Mexico	I
Mexican greater funnel-eared bat	*Natalus mexicanus*	Tropical	I
Ghost-faced or Mustached Bat Family *(Mormoopidae)*			
Davy's naked-backed bat	*Pteronotus davyi*	Tropical	I
ghost-faced bat	*Mormoops megalophylla*	Tropical	I
Parnell's mustached bat	*Pteronotus parnellii*	Tropical	I
Wagner's mustached bat	*Pteronotus personatus*	Tropical	I
New World Leaf-nosed Bat Family *(Phyllostomidae)*			
California leaf-nosed bat	*Macrotus californicus*	NW Mexico & SW US	I
common vampire bat	*Desmodus rotundus*	Tropical	B
hairy fruit-eating bat	*Artibeus hirsutus*	Endemic to W Mexico	FR
highland yellow-shouldered bat	*Sturnira ludovici*	Tropical	FR
lesser long-nosed bat ■ ●	*Leptonycteris yerbabuenae*	Mexico & SW US	N & P
little yellow-shouldered bat	*Sturnira lilium*	Tropical	FR
Mexican long-nosed bat ■ ● ▲	*Leptonycteris nivalis*	Mexico & SW US	N & P
Mexican long-tongued bat ■	*Choeronycteris mexicana*	Mexico & SW US	N & P
Pallas's long-tongued bat	*Glossophaga soricina*	Tropical	N & P, I
Toltec fruit-eating bat	*Artibeus toltecus*	Tropical	FR
Waterhouse's leaf-nosed bat	*Macrotus waterhousii*	Tropical	I
Sac-winged Bat Family *(Emballonuridae)*			
gray sac-winged bat	*Balantiopteryx plicata*	Tropical	I

Common Name	Species	Distribution	Diet
Vesper Bat Family *(Vespertilionidae)*			
Allen's big-eared bat	*Idionycteris phyllotis*	C and N Mexico & S US	I
Arizona myotis (or occult myotis)	*Myotis occultus*	C and N Mexico & S US	I
Baja California fish-eating bat ◆	*Myotis vivesi*	Islands near Baja	F & I
big brown bat	*Eptesicus fuscus*	North America	I
California myotis	*Myotis californicus*	Mexico & W US	I
cave myotis	*Myotis velifer*	Mexico & S US	I
cinnamon myotis	*Myotis fortidens*	Tropical	I
fringed myotis	*Myotis thysanodes*	Mexico & S US	I
hoary bat	*Lasiurus cinereus*	North America	I
little yellow bat	*Rhogeessa parvula*	Endemic to W Mexico	I
long-legged myotis	*Myotis volans*	C and N Mexico & S US	I
Mexican big-eared bat	*Corynorhinus mexicanus*	Endemic to C & N Mexico	I
Mexican free-tailed bat	*Tadarida brasiliensis*	Tropical & temperate	I
pallid bat	*Antrozous pallidus*	C & N Mexico & C US	I
peninsular myotis ▲	*Myotis peninsularis*	S Baja California	I
silver-haired bat	*Lasionycteris noctivagans*	North America	I
small-footed dark-nosed myotis	*Myotis melanorhinus*	C & N Mexico & S US	I
Southwestern myotis	*Myotis auriculus*	C & N Mexico & S US	I
spotted bat	*Euderma maculatum*	C & N Mexico & W US	I
Townsend's big-eared bat	*Corynorhinus townsendii*	C & N Mexico & S US	I
Western long-eared myotis	*Myotis evotis*	Baja California & CA	I
Western pipistrelle	*Pipistrellus hesperus*	C & N Mexico & S US	I
Western red bat	*Lasiurus blossevillii*	W Mexico & SW US	I
Western yellow bat	*Lasiurus xanthinus*	C & N Mexico & S US	I
Yuma myotis	*Myotis yumanensis*	C & N Mexico & S US	I

Conservation status: ■ Threatened in Mexico ● Endangered in the US ◆ Endangered in Mexico
▲ Endangered according to International Union for the Conservation of Nature (IUCN)
I = insects F = fish N = nectar P = pollen FR = fruit B = blood

ISLAND BATS on the Sea of Cortez

Winifred F. Frick, Ph.D.
National Science Foundation Bioinformatics Postdoctoral Fellow, University of California Santa Cruz and Boston University

Photos by Rodrigo Medellín

Photo by Marco Tschapka

Top: Gulf of California islands harbor many endangered species, including the endemic Baja California fish-eating bat. Above and cut out: Huge, elongated claws help these fish-eating bats capture fish and invertebrates on the sea surface.

Sunset on a desert island is a magical experience, as the heat of the day subsides with the setting sun and nocturnal life awakens. On an island in the Sea of Cortez, you might see bats flitting overhead as they emerge from crevices and caves to forage in the night sky. At least twelve species of bats are known to live on these islands, where they make up a large proportion of the native mammalian diversity.

Most islands in the Sea of Cortez, also known as the Gulf of California, have at least a few species of bats, with smaller and more isolated islands harboring the fewest. The diversity of bat species is higher in the southern part of the Gulf, where more rain falls during the monsoon season, contributing to a greater diversity of vegetation and habitat types. This gradient in bat diversity is similar to patterns of bird diversity in the same archipelago. Foraging habits likely influence the distributional patterns of these island bats, and insectivorous bats typically don't live on islands of less than 100 hectares unless they are very close to the peninsular coast.

Bats on these desert islands, as elsewhere, provide vital ecological services ranging from reducing insect populations to pollinating plants and dispersing seeds. A federally endangered species in both the United States and Mexico, the lesser long-nosed bat is one of the most common bats on the islands. Caves on several islands support large maternity colonies of lesser long-nosed bats, which are important pollinators for the picturesque cardón cactus *(Pachycereus pringlei)*. The sweet nectar in cardón flowers also supplements the diet of the pallid bat, which normally feasts on scorpions and other ground arthropods. But most bats on these islands are insectivores that hunt aerial insects such as moths and beetles. Another common island resident, the California leaf-nosed bat, specializes in gleaning insects off plant surfaces.

There are no species of bats endemic to the islands, but there is one island species endemic to the region—the Baja California fish-eating bat. Unique to northwestern Mexico, the fish-eating bat is true to its name, with a predilection for devouring fish. It hunts over calm sea waters at night using echolocation to detect ripples in the water's surface, snaring small fish with its unusually large feet. This species is common on all the Gulf islands; it also inhabits a few islands on the Pacific coast of the Baja California Peninsula but is found nowhere else in the world. It commonly roosts under rocks and in rocky crevices close to the water's edge. One well-studied population inhabits Isla Partida in the Midriff, where several thousand bats roost in rocky interstices underneath a colony of storm-petrels. Female fish-eating bats give birth to a single pup in the spring, and carry their young to convenient night roost caves to wait while they forage out over the sea.

The islands in the Sea of Cortez have served as a natural laboratory for studies on marine and terrestrial ecology for many years, but until recently very little research has been focused on its bats, and many questions remain about the ecology and conservation of bats on islands. Future research on their dispersal and movement among the islands will help determine whether island populations are distinct or connected to coastal populations. Most islands in the Gulf are protected by Mexico's national park system, which shields their bat populations from threats of human disturbance and habitat destruction. However, introduced predators like rats and cats may pose risks to the endemic fish-eating bat, which is unaccustomed to these invasive predators. S

Photo by Rodrigo Medellín

CHIROPTERAN MIGRATIONS
in the Borderlands

Rodrigo A. Medellín, Ph.D.
Director of Science and Conservation,
Arizona-Sonora Desert Museum and Senior Professor of Ecology,
Instituto de Ecología, UNAM, Mexico

The well-being of neighboring countries depends in part upon the migrants between them. Movements across borders, whether of wildlife, people, or products, are often beneficial to both countries.

Take the case of bats along the U.S.-Mexico border. At least 34 bat species inhabit the 2000-mile-long transborder area from Texas to California and from Baja California to Tamaulipas. More than a dozen and possibly up to 20 species migrate from central and southern Mexico to this region for the summer and then return south in the fall, including many millions of insectivorous Mexican free-tailed bats and hundreds of thousands of nectar-feeding bats such as the lesser long-nosed bat and the Mexican long-nosed bat. Fortunately, there is no wall or boundary of any kind, or safety issue, or regulation that can stop them.

Baby lesser long-nosed bats cluster together on the roof of a cave to take advantage of body heat.

Cut out right: Saguaro cactus in bloom.

What would happen if these bats were unable to migrate? Crops in the border region, such as cotton, corn, and other vegetables, would suffer multimillion-dollar losses due to crop pests whose populations would grow unchecked. In time, the native landscape of our charismatic Sonoran Desert would also show severe changes. Although other animals carry out some pollination service for saguaros, organ pipe, and other columnar cacti, bats are essential to their reproduction and genetic diversity, carrying pollen from one plant to others up to ten or more miles away. In fact, feces analyses show that hundreds of thousands of bats roosting in the Pinacate region each summer fly 13 or more miles regularly to feed in and pollinate saguaro flowers close to the border.

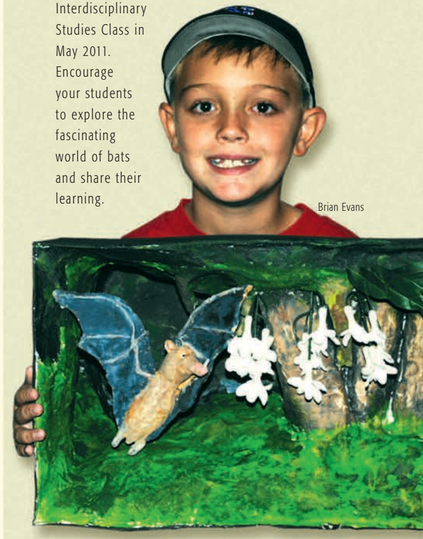
Nectar bats come to the transborder region during the summer because the hot caves they inhabit in our desert region provide them hospitable conditions (including 90°-plus ambient temperatures) for giving birth and rearing offspring. Because they are unable to regulate their body temperature, babies of Mexican free-tailed, Mexican long-nosed, and lesser long-nosed bats, among others, require environments that are as hot as their parents' bodies to survive. So these bats gather in large colonies, producing body heat that gets trapped against the roof of the cave in which they roost.

Most people are not aware of the important roles bats play in maintaining healthy ecosystems and productive crops. Nor do they realize what sensitive creatures they are, or that they can be severely affected by disturbances to their roosts and habitats, including the critical migratory corridors they rely on to travel between Mexico and the United States. Both the U.S. and Mexican governments and private citizens in both countries need to be proactive in securing the long-term health of bat populations in the border region and throughout their ranges. Laws and policies safeguarding habitats, caves, and bats (beyond just the endangered species) are important in achieving this protection. Real protection will take collaborative, government-recognized efforts between both countries. Only an organized, well-designed strategy that brings together citizens, conservationists, government agencies, and bat biologists on both sides of the border can achieve this.

Strong awareness campaigns, educational programs, effective and continuous communication with the federal governments (with all ten border states) are imperative. In southern Mexico, bat biologists have worked in rural elementary schools, providing "bat-pollination" and other games for schoolchildren who previously had known little about and had little sympathy for bats. Years later, when the educators returned, those children's younger siblings already knew about the habits and importance of bats. The teachers and children were passing the information on. There is hope. But there is much to do, and everyone can play a role. Write to your legislators, talk to your leaders, your family, and your friends, and support organizations that work to protect bats. Every contact is important in spreading the word. We must build a critical mass large enough for both countries to act, and we need to start now. S

KID POWER!

Your children can help get the word out, too. When students at Tucson's Sunrise Drive Elementary School were asked to do a report on endangered animals, fourth-grader Brian Evans chose to learn and write about bats. His report "Banana Bats Go Bananas" took a creative angle on telling the story of this endangered nectar-loving bat of the central Pacific coast in Mexico. He imagined two bats "talking" as they observed our bat biologist, Dr. Rodrigo Medellín, doing his research. Brian also built a three-dimensional model of the bat hovering by its favorite meal, which was displayed at the open house of his Interdisciplinary Studies Class in May 2011. Encourage your students to explore the fascinating world of bats and share their learning.



Brian Evans

Photo © BIO

A Waterhouse's leaf-nosed bat has captured a katydid.

ECHOLOCATION:
How Bats "See" the World

Tania Gonzalez-Terrazas, biologist, and **Elisabeth K.V. Kalko, Ph.D.,** Professor, University of Ulm, Germany

The two main evolutionary adaptations that have made bats so successful in populating the nocturnal niche are echolocation and active flight. While bats are unique among mammals in their ability to actively fly, a few other mammals, such as some shrews, toothed whales, and dolphins, use echolocation. But most nocturnal vertebrates are highly dependent on visual cues for finding their way in the dark, and most bats are not. Echolocation allows them to navigate in space and, in many cases, to detect, identify, and locate food in total darkness. Echolocation is a form of biological sonar in which an animal emits high-frequency calls and extracts and interprets information from the returning echoes to navigate and forage.

Depending on where and what they eat and how they acquire their food, bats confront a variety of sensorial challenges. For example, bats that hunt insects on the wing in open space or at forest edges (aerial insectivores) face different conditions than those that search for prey within dense vegetation or take food from the ground or from a water surface (gleaning and trawling bats). Bats flying close to or within vegetation have to discriminate between echoes from potential food items and the multitude of echoes bouncing back from leaves, twigs, and the ground. Often, echoes from sources of food and the ambient background overlap and make the extraction of relevant information difficult for the bats. In that case, bats may use additional cues, such as scent or noises produced by the prey.

The sonic structures of the echolocation calls bats emit also show remarkable diversity, depending on the species of bat and its hunting strategy. Bats have evolved a wide variety of signal types that differ in frequency, duration, harmonic content, and sound pressure (intensity). The general design of the outgoing call determines the type and quality of information contained in the returning echoes. Many bats can change signal structure to accommodate a behavioral situation, habitat, or foraging strategy. Search calls emitted when bats are looking for food differ from approach calls produced while a bat is approaching a target. Aerial insectivores typically emit many very short calls in rapid-fire repetition during the final stage of pursuit, prior to capturing their prey or an attempt to capture.

Echolocation calls often consist of several elements, each providing the bat with a different kind of information. Frequency-modulated broadband signals are well suited for precise target location, whereas narrowband signals facilitate the detection of moving prey. The trade-off between basic detection and precise location is reflected in call structure, as bats that have to perform several tasks simultaneously combine broadband and narrowband elements in their signals.

Whereas call features such as bandwidth, intensity, duration, and pulse interval are mainly dictated by the sensory challenges faced by the bats, other parameters such as peak frequency, harmonics, and sequence of signal components are dictated by phylogenetic differences in the bats. Sometimes echolocation calls are species-specific, which in some areas and situations allows us to identify some species by call.

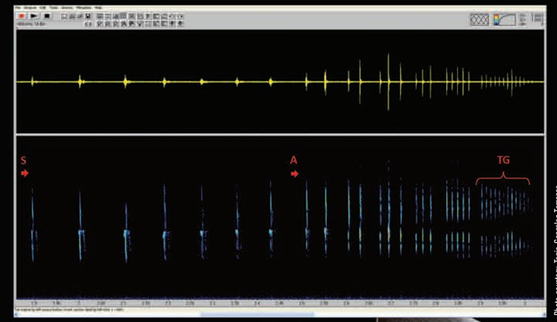


Photo courtesy Tania Gonzalez-Terrazas

A sonogram showing the echolocation behavior of a lesser long-nosed bat approaching a cactus flower. In it, three different phases of emissions are identified: search (S), approach (A) and a distinctive terminal group (TG) that the bat emits before the insertion of the snout into the flower (Gonzalez-Terrazas et. al., in preparation). Right: A pygmy fruit-eating bat *(Artibeus phaeotis)* from western Mexico carrying a tropical fig.

Photo by Angelica Menchaca

Because so much information about foraging behavior, activity, and identity of bats can be derived from the shape and pattern of their echolocation signals, bat researchers increasingly use echolocation as a tool to address relevant questions. Acoustic monitoring permits us to document the presence or absence of a species, as well as its foraging activity, particularly in aerial insectivores that have, so far, been seriously understudied. Recording and analysis of echolocation calls provides detailed information on the habitat use and activity patterns of many species, so acoustic monitoring has become an important component of bat surveys and behavioral studies. These studies open up new perspectives for long-term monitoring programs, and will undoubtedly provide an excellent base for the establishment of comprehensive programs for bat research and conservation. S

Karen Krebbs with lesser long-nosed bat.

Karen Krebbs, bat biologist at the Desert Museum, uses both acoustic monitoring and mist netting in her research. Over the last 12 years, she has monitored bats in northern Mexico; in the Chiricahuas, Huachucas, and other sky islands of southern Arizona; at the Muleshoe Ranch; in Aravaipa Canyon; and in several National Parks, including Organ Pipe and Tumacácori. She has also monitored in the Tucson vicinity, including the Sweetwater Wetlands and Agua Caliente Park. The extensive data she has gathered is currently being compiled into a database for the National Park Service, Arizona Game and Fish Department, and The Nature Conservancy. S

Chinese bat circle pedestal.

Photo by Rodrigo Medellín

BATS & PEOPLE

Photo courtesy of J. D. Pettigrew, Professor Emeritus, Queensland Brain Institute.

Laura Navarro
Environmental Education Specialist, PCMM/Bioconciencia, Program for the Conservation of Mexican Bats

Bats and human beings have been living together ever since *Homo sapiens* has walked this planet. Over the millennia, bats have been influencing not only our ecosystems but also our perspective of nature, our beliefs, and our behaviors. In many cultures across the globe bats play a crucial role in religion, art, or literature; they have also been the subject of consequential scientific investigations. Exploring our past helps us understand how important these extraordinary flying mammals have been to humans.

ANCIENT & OLD WORLD

Representations of Bats

We find representations of bats in many ancient cultures. One of the earliest indications of the importance of bats in the lives of our late Palaeolithic ancestors was recently found near Kalumburu, Australia; eight beautifully painted white-striped flying foxes, a type of fruit bat, have been roosting peacefully in a cave for more than 20,000 years.

Some of the most amazing representations, dating from about 2,000 BCE, are in the tomb of Baket III in Egypt, where bats surrounded by birds were carefully detailed, allowing us to assume that whoever crafted them had the opportunity to observe them closely.

Bats also make an appearance in some of the greatest literary works in history. In Homer's *Odyssey,* Hermes speaks of bats hanging from their legs and living in groups. In *Metamorphosis,*

EDI

Courtesy New York Public Library digital gallery

EDI

Photo by Rodrigo Medellín

Opposite page top: Cave paintings of white-striped flying foxes more than 20,000 years old, found near Kalumburu, Australia. Above, in order from left to right: Traditional wooden decorative plaque depicting Chinese symbols of prosperity, including the character "Fu" and the bat, whose name is pronounced similar to "Fu," ie a visual pun; Archeological recordings from *I monumenti dell'Egitto e della Nubia* (1832-1844) by Ippolito Rosellini depicting art in an ancient Egyptian tomb, including drawings of anatomically correct bats; A fountain featuring a bat in Rome, Italy, dating from 1586, restored in 1733; Chinese golden carved bat in the Forbidden Palace, Beijing. Below right: A bat profile shows up in the Mayan glyph in the corner of this inscription. The bat glyph is common in the Classic Mayan period.

Ovid recounts a Greek myth in which the three daughters of King Minyas of Orkhomenos, the Minyades, were transformed into bats after refusing Dionysus's command to join an orgy.

In one of Aesop's fables, a bat is caught twice by a weasel but cleverly escapes, first by telling the weasel he was a mouse and then that he was a bird. In another fable, a bat loses all its money after a shipwreck, and to avoid conflict with its associates, it has been hiding during the day ever since then. In a third fable, a bat hesitates about whether to join the army of the beasts or the army of the birds and ends up alone. These stories are fanciful explanations of chiropteran or bat characteristics.

Aristotle correctly classified bats as warm-blooded animals, and he concluded that when bats leave their roosts in large groups, the following day would be warm and calm, but when they hide and do not appear at sunset, a stormy or a cloudy day would follow. In fact, bats are less active on stormy nights than on calm and dry nights.

POPULAR MYTHS

During the Middle Ages, bats were considered mysterious and evil creatures associated with witchcraft and sorcery; they represented messengers of the Devil. Because bats were difficult to notice and catch, people believed they had the ability to become invisible; some people even believed that hanging a bat's eye around one's neck would grant that person the power of invisibility.

As ridiculous as these ideas might seem to us nowadays, current misconceptions about bats are equally unfounded. Bats are still poorly understood by the general public, and some myths still hold sway. For example, it is common to hear that bats are blind and hairless creatures that transmit fatal diseases to man, or that they bring bad luck, or that they attack women's hair. It is almost shocking to know that they are still used as key ingredients in potions concocted to make a person fall in love or to punish someone.

Undoubtedly, the Bible has influenced attitudes toward bats in western cultures. In Leviticus (11:13–19) and in Deuteronomy (14:11–18) bats fall under the umbrella of abhorrent, unclean birds that men should detest and avoid eating (as do vultures, sea gulls, raptors, and long-legged birds, among others). In the Talmud, a book of Hebrew religious teachings, several passages describe the nature of bats. For example, in one Bava Qamma it states that after seven years hyenas turn into bats and after additional seven-year periods they turn into thorns and demons. Another entry says that bats live for 30 years, lay eggs, and drink milk. As mammals, baby bats do drink milk, of course, and although some bats may have lived up to 30 years, few species have a lifespan of more than 10 to 20 years; and no bats lay eggs.

Photo courtesy of Laura Navarro.

Courtesy the Metropolitan Museum of Art, New York.

Photo by Rodrigo Medellín

Photo by Laura Navarro

BATS IN THE PRE-COLUMBIAN NEW WORLD:

Perceptions and Iconography

Representations of bats in the New World have been found in buildings, crafts, and paintings of ancient cultures. Some of the most remarkable include the zoomorphic figurines of the pre-Columbian Toltec culture found in the Palace of Tetitla, about 30 miles north of Mexico City, and in the traders' neighborhood of Teotihuacan. According to an iconographic analysis, these figurines represent real chiropterans. Archaeologists also found a ring used for the Mesoamerican ballgame in Xochicalco crafted in the shape of a bat. And more recently, a large ceramic figure more than six feet tall was found in Miraflores, Morelos, at the foot of the Popocatepetl Volcano. It has a bat head with a human body, and the clawed feet and the hands of a bat. According to archaeologist Francisco Hinojosa, this figure represents a Bat God.

One of the most representative pieces of the Zapotec civilization is without doubt the jade burial mask found in Monte Alban, Oaxaca, which displays the characteristic shape of leaf-nosed bats. It is considered one the most important representations of the Bat God, and is an extraordinary piece of Mayan history and art. Funerary urns, including two representing *Piquete Ziña,* the Bat God, also came from the Zapotecan culture, and several bat-themed ceramic pieces found in central Veracruz from the Classical Period (600–1500 AD) are on display in the Anthropology Museum of Xalapa, Veracruz.

There are many representations of bats in the Mayan culture. One of the most impressive is the sculpture *Qaaw'a Sotz,* "Lord Bat" in the Q'eqchi' Maya language, found at Copan. It represents a mythic being with human body, bat head, and wings, dressed with a loincloth that hangs down to its feet. Another beautiful piece is a whistle in the shape of a bat found at Jaina Island, Campeche. Paintings on ceramic pieces are also common in Mayan art, such as a plate with a painting of four bats recently found in Balam-Kú, Campeche. During the Classical Period (450 AD) Mayans produced intricate relief carvings that either adorned buildings or stood alone as stelae; some of these take the shape of bat heads. In addition, the hieroglyphic symbol of the City State of Copan is the face of a bat, clearly identifiable by the leafed nose and the tragus.

In the Haab', the Mayan solar calendar of eighteen months, each month had a patron god that influenced each day with its particular supernatural powers. During the month of *Tzotz,* "The Bat God," beekeepers prepared themselves for the coming activities by fasting. It may have also been associated with the beginning of the darkest months of the year in the winter.

Though bats are frequently represented in Mesoamerican codices, it is difficult to establish the connections they had with other gods and the role they played in the Mesoamerican way of thinking. In the Fejé Èrváry-Mayer Codex, the Vaticanus Codex, and the Borgia Codex representations of the man-bat, better known as *Tzinacantli,* the Nahuatl word for bat, relate to beheadings and death. The *Mapa Tlotzin,* a painted manuscript, tells the story of a Nahua group from its settling to the reign of Nezahualpilli. In one of the paintings a bat stretching its wings hangs at the top of a cave.

The sacred Mayan books, The Book of *Chilam Balam* and *The Popol Vuh,* contain numerous stories and descriptions of bats. In these books, both caves and the Mesoamerican ballgame represent the entrance to the underworld; in the game, the losing team was decapitated as a ritual sacrifice for the gods. Bats were commonly associated with the underworld and played a role as decapitators in some of the characters of the books.

FACTOID

Feeding on blood is not unique to bats, but is a fairly common strategy used by many arthropods, as well as some human cultures such as the Masai in Africa.

Top left: Etching by Francisco Goya, "The Dream of Reason Produces Monsters," from Caprices, No. 43. 1796. The message in Spanish reads, "Fantasy abandoned by reason produces impossible monsters: united with her, she is the mother of the arts and the origin of their marvels." Left: Decorative stone carving in in the Summer Palace, Beijing, China. Cut out above: Pre-Columbian ceramic figure of a bat from Los Cerros, Veracruz, on display at the Museum of Anthropology at Xalapa.

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Photo © George DeLange

Photo by Rodrigo Medellín

BAD BATS, GOOD BATS

Europeans arriving in the New World also chronicled bats. Some observers described insectivorous bats and some told stories of larger and "tasty" animals, which may refer to frugivorous bats. One kind of bat, however, was particularly described: the hematophagous, or vampire, bats. They told how these animals bit humans on their toes and how calves bled to death after being attacked by vampire bats. Not surprisingly, sensational reports of this sort spread, raising fears and leaving little sympathy for any bats in the public conscience, if not engendering an active desire to kill them.

One of the most influential twentieth-century literary works was Bram Stoker's 1897 book, *Dracula,* one of the most famous horror novels of all time. Interestingly, Stoker played on two anecdotes from articles he'd reviewed, one of which was a newspaper article with a description of a vam-

Top right: Detail of a bat on the top of Mercado de Colón in Valencia, Spain. A bat *(Rat Penat)* is the animal in Valencia's coat of arms and it appears in multiple representations throughout the city. Middle: Decorated door of a temple in Laos. Cut out: The Jade Mask of the Bat God is a splendid example of Zapotec archeology and art. It was found in Monte Alban, Oaxaca. Right: Chinese green gate with carved bats, Summer Palace, Beijing, China.

Photo by Rodrigo Medellin

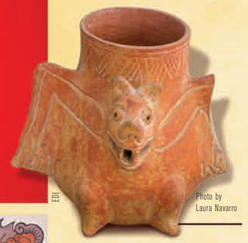

Photo by Laura Navarro

"As they sought the dark,
a skinny membrane spread down
their dwarfed limbs and wrapped thin wings
about their tiny arms....
Not with feathered plumes they ride the air,
but keep themselves aloft on parchment wings,
and when they try to speak
they send a tiny sound that suits their
size....
From dusk they take their name
and flit by night."

—Melville translation of Ovid's "The Daughters of Minyas" from *Metamorphosis,*
Oxford University Press, Oxford, 1986.

Upper left: Chinese traditional door and knocker in Beijing,China. Middle: Chinese lion on a cloud encircled by bats. Bottom: Some bat fans express their admiration with a bat tattoo. This one shows a lesser long-nosed bat at a saguaro flower. Cut out: Pre-Columbian incense burner with bat motif.

pire bat attacking a cow in Argentina. After his book was published, the bat's association with vampires, night, and terror became entrenched in the modern mind. Beyond the impact of the novel, cinematographic versions of the book, particularly *Nosferatu,* left a bad perception of bats in the collective subconscious of the Western world. This 1920s German horror movie spawned countless vampire movies through modern times, associating vampires, bats, and evil. Beginning in the mid-twentieth century, however, young people in North America drew a more positive association from comic books and movies of "Batman," who uses the cover of night to do good deeds. Clearly, bats have had mixed reviews; in some corners of the globe, they have even been associated with good luck.

In recent centuries, bats have also been an inspiration for a great number of literary works, such as *Don Quixote, The Adventures of Tom Sawyer,* and the poems of Sor Juana Inés de la Cruz, not to mention the new Silverwing series, in which anthropomorphized bats drive the novels. Popular literature often expresses the knowledge or beliefs in the author's world; in many cases, the inclusion of bats functions as a literary device to imprint drama, suspense, fear, or terror. Sometimes bats are treated as characters whose features have nothing in common with the real features of bats.

Eastern cultures such as China and Japan deserve special mention because, for them, bats represent good fortune; they are linked to happiness, and representations of them can be found in religious temples and in many common objects like plates, buttons, handles, and even in clothing and shoes. The Chinese symbol Wu Fu (five bats), frequently used today in various artifacts and ornaments, represents good health, wealth, longevity, good luck, and tranquility. It is said that Japanese artisans designed their paper fans based on the way bats open and close their wings.

Throughout history, open-minded people have shown a positive interest in bats. Leonardo Da Vinci realized bat wings were much more suitable for flight than bird wings, and he used them as inspiration for the design of a flying machine. Years later, with Da Vinci's designs, Clement Ader became the first man to rise from the ground using a steam-powered machine that moved similarly to bat wings. In the twentieth century, the study of bats contributed to the design of radar systems used in submarines, ships, and aircraft. More recently, the components of the saliva of vampire bats have been studied to design a drug, Desmoteplase, that can break up blood clots for the prevention of fatal strokes.

Bats are present in many cultures and have touched the imagination and lives of many people. As we learn more about them, their place in the natural world, and the benefits they provide for us, perceptions of bats will undoubtedly become more positive. With outreach programs in the schools and environmental articles in the media, there is hope that public sympathies around the world will move increasingly toward bat conservation. S

Bat Programs & Organizations

Arizona Game and Fish Department Bat Group
http://www.azgfd.gov/w_c/bat_conservation.shtml

Bat Conservation International
http://www.batcon.org/

EuroBats http://www.eurobats.org/

IUCN Bat Specialist Group http://www.iucnbsg.org/

Latin American Network for Bat Conservation/RELCOM
http://www.relcomlatinoamerica.net/

North American Symposium on Bat Research
http://www.nasbr.org/

Program for Conservation of Mexican Bats/ (PCMM)
http://pcmm.bioconciencia.org.mx/

Western Bat Working Group http://www.wbwg.org/

Year of the Bat http://www.yearofthebat.org/

Photo by Rodrigo Medellin

Photo by Cindy Clapp

Photo by Rodrigo Medellin

Photo by Rodrigo Medellin

Top right: Bat emergence from under the bridge at Campbell and River in Tucson, Arizona. Middle: Chinese dishes with bat motif. Bottom: Contemporary Balinesian bat carving from the village Tegalalang. Cut out: Contemporary Chinese decorative hanging with bat motif.

BATS & BAT HOUSES

Amy Turmelle, Ph.D.
Centers for Disease Control and Prevention

Photo by Karen Krebbs

Photo courtesy University of Florida, Gainesville

Bat houses at the University of Florida in Gainesville, Florida, host tens of thousands of bats and are a local attraction.

Photo by Karen Krebbs

Middle: Bat houses provide roosting space for bats and increase public awareness about the roles bats play.
Right: Bat houses can be installed in a variety of locations, from exterior walls to poles, to trees.

Bats live in a variety of habitats, including natural roosts such as caves, tree cavities, and rock crevices. Some bat species can also tolerate living in man-made or artificial roosts, such as buildings, bridges, culverts, and bat houses. As natural bat habitats have been increasingly destroyed or altered across the landscapes of North America, the number of bats relying on and inhabiting man-made roosts has grown. Bat houses have been constructed in natural parks to increase the number of bat habitats available, and some individuals have constructed bat houses in their yards to provide an alternative to bats roosting in their attic. In some agricultural settings, bat houses have been put up to promote insect control, whereas other bat houses have been erected for exhibit purposes, as a tourist attraction. While all of these uses promote the conservation of these unique animals, bat houses as tourist attractions are particularly important because they increase the public's understanding of bats. But bat houses alone are not enough. It is also important to provide educational outreach.

For example, the University of Florida in Gainesville has a bat house that is home to tens of thousands of Brazilian free-tailed bats *(Tadarida brasiliensis)* and a few hundred southeastern myotis bats *(Myotis austroriparius)*. This bat house has a fence around it to keep humans from disturbing the roost and to keep them away from the fecal material that accumulates underneath. It also has another "buffer" fence to keep observers at a healthy distance while they watch the bats emerge from the roost to forage on insects around campus—a nightly attraction. In the observation area, which is frequented by 20 to 50 persons on many nights, educational signs introduce bats and their benefits to the local ecosystem while also highlighting precautionary statements about avoiding direct contact with the bats, as with any wildlife. The University of Florida bat house is a good model of how to construct an exhibit that operates to protect the public and the bats themselves.

FACTOID

Bats tend to be very long-lived for such small mammals with extremely high metabolisms, many species living 10 to 20 years.

In recent decades, public health recommendations regarding contact with bats and bat habitats have come into greater focus. Most of these guidelines address prevention of rabies, which can be transmitted by bats as by numerous other animals. Recommendations initially published in 1999 by the Advisory Committee on Immunization Practices (ACIP) emphasized the importance of seeking medical advice if you think that you have had contact with a bat. Guidelines published in 2008 by the National Association of State Public Health Veterinarians (NASPHV) recognize that public exhibits of bats can serve an important educational tool and provide a few guidelines to help steer the public away from direct contact with the animals (e.g., handling and touching of bats). These recommendations are meant not to discourage the use of bat houses by the public or by institutions for educational purposes, but merely to encourage a healthy respect in our interactions with bats and other wildlife. Today, it is important to increase public awareness about the role bats play in the overall ecosystem and the need to protect them from threats causing high mortality, such as wind turbines and White-Nose Syndrome. S

Right: ASDM bat specialist Karen Krebbs has been working with bat houses for years.

Building Bat Houses

If you'd like to host bats in your backyard, there are numerous authoritative guides to building or purchasing bat houses. Check the following websites to learn more:

U.S. Fish and Wildlife Service
http://www.fws.gov/Asheville/pdfs/beneficialbats.pdf

National Wildlife Federation
http://www.nwf.org/Get-Outside/Outdoor-Activities/Garden-for-Wildlife/Gardening-Tips/Build-a-Bat-House.aspx?CFID

Bat Conservation International
http://www.batcon.org/pdfs/bathouses/bathousecriteria.pdf

Photo by Merce Tschapka

BAT CONSERVATION:

Priorities and Initiatives in the Sonoran Desert Region

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Bat Management Coordinator, Arizona Game and Fish Department

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Supervisory Fish and Wildlife Biologist, U.S. Fish and Wildlife Service

Bats have been on our planet for more than 50 million years, long before humans walked the Earth. Today, however, many species of bats are threatened with extinction. Like other wildlife, bats suffer from habitat degradation and destruction. They are also threatened where they live, forage, and travel—from deliberate acts to diminishing resources. Important predators of night-flying insects as well as pollinators and seed-dispersers of iconic Sonoran Desert plants, bats need our help and protection now more than ever.

Bat needs are analogous to basic human needs, which include year-round safe housing, clean water, and sufficient food. They also require safe passage from their roosting to their foraging sites. Unfortunately, many species of bats known from the Sonoran Desert, like bats elsewhere, face numerous negative impacts including:

- loss of roosting habitat
- reduced water quality and/or availability
- declining food resources
- threats to daily and/or seasonal travel

A HOME OF THEIR OWN—
It's Not Just about Caves

When we think of bats, we often think of caves. Many of us have seen spectacular images of large emergence flights from places like Carlsbad Caverns, but there are many species of bats that rarely, if ever, enter caves. Big free-tailed bats roost in cliff crevices high in mountain canyons. Their wings are so long and narrow that they must drop from great heights and spread their wings before they can gain flight.

Other species live in trees, either in natural cavities or those excavated by other animals. Big-eared bats can live in the cave-like basal hollows that form in large old-growth trees. Big brown bats have been known to roost in saguaro boots. Still others hang right out among the leaves of trees. Yellow bats roost in the dead fronds of wild palms or in dried skirts of soaptree yuccas. Pallid bats and Mexican long-tongued bats will use rock crevices or small erosional caves hollowed out by wind or water along washes.

As humans have altered cave habitats and logged forests, many bats have lost their natural roosts. These bats have learned to use man-made structures for roosts. Some of our most familiar bats, like little brown and Mexican free-tailed bats, have adapted to live in attics, barns, old wooden buildings, bridges, and abandoned mines—structures that approximate the conditions bats found in their traditional forest and cave habitats.

Wherever bats roost, they have critical thermodynamic needs. Maternity colonies of most species must be warm and in habitats with rich food resources so young can grow and develop rapidly. Hibernation sites on the other hand, which some bat species of the Sonoran Desert Region use to survive the winter, must be cold but with stable temperatures that don't drop below freezing. This allows bats to reduce their metabolisms and survive an entire winter without food, using just 5 to10 grams of stored fat (roughly the weight of 5 to10 plain M&M candies).

Photo © BCI

Photo © BCI

Photo © Merlin D. Tuttle

Opposite page: Pallas's long-tongued bat drinking nectar from the flower of a morning glory tree. Top: Western yellow bat in palm frond. Bottom left: Hoary bat in oak tree. Bottom right: Pallid bats seek their prey on tree trunks, vegetation, or rocky substrates.

Top: A Townsend's big-eared bat catching a drink of water. Bottom left: Mexican long-tongued bat drinking from hummingbird feeder. Bottom right: This stock tank/water-for-wildlife tank in the Chiricahua Mountains was installed through a joint effort by BCI, the USDA Forest Service, Bureau of Land Management, and the Arizona Game and Fish Department. Thirteen of the area's 21 bat species have been caught over the tank since it was rehabilitated with an "escape ramp." The ramp can be easily be constructed by bending a small sheet of expanded metal and affixing it to the lip of the tank, leaving no gaps that can trap bats (or other wildlife) and providing a "grippy" surface to climb.

Disturbance in caves and mines can be deadly. Any disturbance of bats during the winter costs each bat its precious fat reserves. Disturbance of maternity colonies in the summer can be just as fatal. Mothers can be startled and fly suddenly from the roost, bumping flightless young who fall to the cave floor and perish. Illegal border activity also contributes to roost disturbance, because border crossers often use caves and mines for shelter.

LIQUID GOLD—
Bats on the Western Water Front

A growing threat to our desert bats is a decline of water resources stemming from myriad factors, including declining water tables due to drought and over-grazing (which depletes the grasses that help recharge groundwater), the damming of rivers, and large-scale irrigation projects.

Unlike most terrestrial wildlife, bats drink on the wing. They swoop low and slow over pooled water to grab a drink. But bat species differ in whether or how they access water resources of various sizes, according to their flying abilities. One of the most commonly used water sources for bats in the Sonoran Desert are the numerous stock tanks on public and private rangeland. A recent Bat Conservation International (BCI) study evaluated over 500 livestock waters in the Southwest and found that more than 50 percent had obstructions that would render them useless to bats attempting to drink. More than 90 percent had no proper wildlife escape ramps, causing bats and other wildlife to drown. These losses are especially unfortunate because they are easily avoidable. Simply keeping water levels full, keeping water surfaces free from obstructions, and installing escape ramps would benefit many bat species and other wildlife in the Southwest. And redesigning livestock and wildlife water tanks would significantly improve bat survival. Urban and suburban residents in the Sonoran Desert can help, too. Conserving water by landscaping with native plants, harvesting rainwater, and using water-friendly technology helps the entire desert ecosystem and all plants and wildlife within it.

> *Bats have such high energy demands that if a nursing mother cannot locate food for two days she will starve.*
>
> FACTOID

WINDS OF CHANGE—
Dangers on the Landscape

Bats' needs vary by season. Some species hibernate to survive the winter, when food resources are insufficient. Other species migrate south to warmer climates where food is available. Nectar-feeding lesser long-nosed bats have been documented making annual migrations of more than 1,000 miles to travel from summer maternity sites in southwestern Arizona and northwestern Mexico to winter sites in western and central Mexico. Migration distances vary by species.

On their migration routes bats need a reliable supply of suitable roosts, food, and water. But those resources are increasingly threatened. Pesticide use decreases foraging opportunities for insect-eating bats, and land conversion that reduces populations of columnar cacti and agave can leave nectar-feeding bats with little to eat. One of the biggest threats to our migratory nectar bats is agave cultivation for tequila production, which leads to food gaps along large stretches of their migratory corridor. Because the agave used to produce tequila is typically prevented from flowering, bats reaching these areas are unable to find food. Fortunately, BCI and others have worked with growers to plant "hedgerows" of native agave that will be allowed to flower. This keeps the nectar corridor intact and provides migratory bats with essential fuel to reach their destinations.

Another danger is the proliferation of electricity-generating wind turbines. Although they are considered a source of "green energy," there is an ecological cost associated with wind turbines, which have been found to cause significant mortality in migrating bird and bat

Top left: Wind turbines have caused significant mortality in migrating bird and bat populations. Top right: Cow walking through an agave field grown for tequila, where the agave plants are prevented from blooming and thus are useless as food for bats. Bottom: Ghost-faced bats roost in large numbers in caves.


Photo by Karen Krabbs


Photo by Rogelio Manrique


Photo by Rodrigo Medellin

Top left: Man made bat roost attached to a palm tree. It appears that bat houses on trees, however, are not as successful as those on walls. Top right: Lesser long-nosed bat with pollen on its head. Bottom: Bats emerging in large numbers from a cave in Mexico.

populations. Thousands of bats are killed by turbines annually. Tree-dwelling species may be attracted to turbines because they resemble large tree snags that are attractive roost sites. Beyond direct collision with blades (which have tip-speeds up to 200 mph), researchers have found that a change in air pressure near the blades causes fatal internal bleeding in the small-bodied bats. The placement of wind farms, avoiding areas that are important to bats and other wildlife, will be critical in reducing deaths, as will curtailing turbine use during peak migration periods. Luckily, many wind energy corporations are interested in working with conservationists to solve this emerging problem. Bat Conservation International has a strong program to help and has provided guidelines for mitigating the effects of wind turbines. In Arizona, the Game and Fish Department also has "wind-wildlife guidelines" to help developers examine potential impacts of their projects on wildlife and to guide essential monitoring studies that should occur before and after construction.

WHAT CAN YOU DO
and Why Should You Care?

Because bat success depends on many factors affecting summer and winter roosts, water resources, food availability, and safe movements, anyone can help to increase the survival of bat populations by simply improving the availability of just one of those resources. As individuals or through community action and conservation organizations, we can maintain reliable water sources. We can also create man-made roosts such as bat houses as a stop-gap until natural roosting resources can be restored. Much can be accomplished simply by encouraging and sharing an appreciation for bats and their critical contributions to the Sonoran ecosystems. Already, outreach programs are changing long-held prejudices that have threatened bats in the past.

In the Sonoran Desert Region several programs engage the public and educate professionals. A citizen-science project in southern Arizona (conducted by the Arizona Game and Fish Department [AZGFD], the U.S. Fish and Wildlife Service [USFWS], the town of Marana, BCI, the University of Arizona, and others) asks residents to collect data on the visitation at hummingbird feeders by nectar feeding bats in the late summer within the range of the lesser long-nosed bat. We are learning when the bats arrive and leave each year and whether and how the bats supplement their natural diet by visiting hummingbird feeders. The more we know, and the better we understand bats, the better we can accommodate their needs along with ours.

Another conservation initiative for bats in the Sonoran Desert Region is a joint education and training program begun in 2008 by the Mexican nonprofit organization Naturalia and USFWS. Each year, two or more workshops or training field trips for university students and young wildlife biologists are held in Sonora or adjacent Mexican states on research, management, and conservation of bats. The goal of these workshops is to build local capacity for bat conservation and to train biologists to educate the general public on the important role bats play in the Sonoran Desert ecosystem. Since 2008 new partners have joined this effort, including BCI, AZGFD, the National Autonomous University of Mexico (UNAM), and the Arizona-Sonora Desert Museum.

FACTOID

Bats are not related to mice, but shrews and moles and bats evolved from a common ancestor living 60 or 70 million years ago.

We've made great strides in the past ten years for at-risk bat populations, but the emerging threats of wind power, climate change, and increasing human populations in the Sonoran Desert continue to challenge us. Please help make it possible for these fascinating and important animals to survive and contribute to Earth's ecosystems for another million years. It is our turn to pay tribute to what these bats do for the ecosystem and for our society. S


Photo by Brock Fenton


Photo © John Ohmer/BCM


Photo © BCI


Photo by Winifred Frick

Top left: The tri-colored bat *(Perimyotis subflavus)*, an insectivorous bat common in the East from Canada to Mexico and Central America, is thought to roost in foliage or tree cavities. Top right: Janet Tyburec of BCI with bat workshop participants near Portal, Arizona. Janet is demonstrating how to safely remove bats from mist nets and handle them properly so they can be identified, measured, and recorded. Bottom left: Pallid bats hanging from rafters in a shed. Bottom right: Lesser long-nosed bats are powerful fliers, migrating over 1,000 miles each year.

Photo by Alan C. Hicks

Photo by Alan C. Hicks

Top: Northern long-eared bat *(Myotis septentrionalis)* infected with White-Nose Syndrome. Characteristic white fungal growth is visible on forearm, ears, and nose areas. Bottom: Pile of bat bones in bat guano, demonstrating the severity of mortality associated with WNS, at Aeolus Cave in Vermont. Cut out: A cluster of little brown bats in hybernation in Aeolus Cave, Vermont.

WHITE-NOSE SYDROME: *A Threat to Hibernating Bats*

Photo by Marianne Moore

Winifred F. Frick, Ph.D.
National Science Foundation Bioinformatics Postdoctoral Fellow,
University of California Santa Cruz and Boston University

In the winter of 2007 while surveying caves and mines where bats hibernate, bat biologists near Albany, New York, saw something they had never seen before—piles of dead bats on the cave floors and an unusual white growth on the faces and wings of hibernating bats. Bats had also been seen flying around in mid-winter. These were the first indications of what is now known as White-Nose Syndrome (WNS), an infectious disease that is causing the most severe population declines of bats in North American history.

WNS is associated with a recently described fungal pathogen *(Geomyces destructans),* which grows best in the cold temperatures preferred by bats during hibernation (39º–59º F). This fungus causes a skin infection that invades the dermis and epidermis, filling sweat glands and hair follicles with fungal growth. Why this fungal infection kills the bats is still being researched, but it appears that infected bats wake too frequently during their winter hibernation and starve to death before spring. Experts have estimated that over one million bats died in just the first couple of years of this disease epidemic.

The pathogen has spread rapidly across eastern North America since its initial discovery near Albany. By spring 2010, *G. destructans* had been detected throughout the northeastern United States into Tennessee, as far west as Oklahoma, and into Quebec and Ontario in Canada. Early reports in 2011 indicate its march into Indiana and North Carolina. All six species of hibernating bats in the Northeast—little brown myotis *(Myotis lucifugus),* northern long-eared myotis *(M. septentrionalis),* eastern small-footed myotis *(M. leibii),* Indiana bat *(M. sodalis),* tri-colored bat *(Perimyotis subflavus),* and big brown bat *(Eptesicus fuscus)*—have shown signs of infection, although some species appear to have higher mortality rates from the disease than others. Three additional species—gray myotis *(M. grisescens),* southeastern myotis *(M. austroriparius),* and cave myotis *(M. velifer)*—have been detected with the fungus, but have yet to show clinical signs of the disease. The little brown myotis, once the most common species in the Northeast, has sustained the highest rates of mortality and may soon face extirpation in that region if mortality and spread continue unabated.

There is much concern and speculation about the potential impact of WNS on bats in the western United States and into Mexico. It seems only a matter of time before the fungus spreads throughout the continent. Winter ecology of bats in the West is poorly understood, and researchers know less about the size and locations of hibernating colonies of bats west of the Rockies than in eastern North America. In general, hibernating colonies in the West seem to be smaller and more spread out than in the East. If densities of bats at hibernacula matter for disease transmission, these populations could be less threatened. Areas with milder winters may also allow bats to forage during mild winter weather. The high diversity of bats in the Sonoran Desert Region makes it an area of particular interest and concern for how this disease may spread into new environs. Early monitoring programs to detect the arrival of WNS and assess population impacts will be critical to determine the degree of its threat in the Sonoran Desert Region. It is premature to predict the impact that WNS may have there, but in the Northeast it remains the greatest threat to bat conservation in our time.

Many agencies, including the National Park Service and U.S. Forest Service, have begun to restrict cave tourism and caving activities as precautionary measures in preventing the potential spread of *G. destructans* by humans. Bats are likely the primary agents of dispersal among caves, but humans may have played a role in the large geographic leaps in the distribution of the fungus. These agencies recommend that people visiting caves not wear clothes or boots that have been worn in a WNS-infected area, and that cavers and bat researchers adhere to the decontamination protocols available on the U.S. Fish and Wildlife website (http://www.fws.gov/whitenosesyndrome/). S

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BATS & RABIES

Rabies is one of the oldest diseases known to man. Around 2,300 B.C. scribes in Eshnunna, Babylon, recorded fines to dog owners for deaths caused by the bite of mad dogs. While rabies in domestic pets has been largely curbed in many countries, rabies persists among wild populations of carnivores, such as foxes, coyotes, raccoons, skunks, and bats (including those bats that have diets of insects, fruits, or blood). In the United States, rabies occurs in all states except Hawaii. All mammals (including ourselves) are susceptible to the disease, which is typically transmitted by the bite of an infected animal. Other routes of transmission are possible (e.g., oral ingestion of infected tissues or organ transplantation from an infected donor), but all other routes are insignificant when compared to transmission by bite.

There is general misconception about rabies in bats, including an incorrect belief that the incidence of infection is uniformly high among populations of bats. In fact, scientists know from extensive surveillance of bat populations over the last half-century that the typical incidence of infection in natural populations is less than one percent. That is, only a *very* small fraction of these flying mammals are capable of transmitting the disease (i.e., are rabid). In the United States, among bats that come into contact with the public and are submitted to state public health departments for rabies testing, the proportion infected is slightly higher, at four percent to six percent of animals tested—still a small fraction, given that the circumstances of human contact may warrant further investigation. (However, this percentage can vary widely among different species of bats.)

Due to the serious nature of this disease, of course, it is always best to seek medical advice if you have been exposed to a suspect animal. On average, two to four humans die of rabies each year in the United States (total, not necessarily from bats). These deaths represent individuals that did not recognize their exposure or did not seek treatment following exposure. Seeking timely medical advice and treatment is critical. In the United States, an estimated 35,000 people are treated with post-exposure prophylaxis each year. With timely treatment, the disease is completely preventable. Treatment includes thorough cleansing of the wound and surrounding area with soap and water, as well as timely vaccination, including a series of four injections of vaccine and separate injections of anti-rabies antibodies to help fight off early stages of viral replication.

In summary, although rabies is a very serious disease, generally only a small fraction of wild carnivores and bats transmit the virus. We also know that bats perform a variety of invaluable ecosystem services, including insect control, pollination of plants, and seed dispersal that can lead to forest regeneration. Therefore, it is incumbent upon us to take precautions to observe and appreciate wildlife in a safe manner, avoiding direct contact and confrontations. Because rabies can lead to unnatural behavior in an infected animal, it is important to *stay alert and be wary of wild creatures that seem to be disoriented, paralyzed, or indiscriminately aggressive.* By taking a few responsible precautions, we can help to prevent exposures to this ancient disease. S

Cut out above: A figurine from the Neo-Babylonian Dynasty (700-500 B.C.) representing a rabid dog. This terracotta animal is in the Mesopotamian collection of The British Museum. Used with permission.

Pallas's
long-tongued bat

Photo by Brock Fenton

THE FUTURE:
Bat Research & Conservation

Gerald Gunnawa Carter, Department of Biology, University of Maryland

LOOKING FORWARD

What can we say about the next 20 years of bat conservation and research? Our predictions about the future of science tend to look humorously inaccurate in retrospect. Modern science has produced the internet, genetically engineered food, and human genome sequencing, but not much in the way of interstellar space travel. Our ineptitude in forecasting advances in science and technology is largely due to the fact that scientific research is so opportunistic. Its direction is driven not merely by what progress we want to see, but often by opportunities opened by unforeseen advances in technology. New cohorts of tech-savvy young scientists are continually exploring topics never before possible. In the science of bat research and conservation, new technologies are paving the way to answer some of our biggest questions. By learning more about bats, we can better understand and address threats to their survival and to the roles they play in healthy ecosystems. By looking at the intersection of the most pressing questions and the fastest-growing technologies, we can identify a couple of research avenues that promise great returns.

In the past, biologists studied bat movements by banding many bats and hoping that someone somewhere would catch those same bats. As you can imagine, it wasn't very efficient. Today, researchers are investigating the patterns of bat movements through a variety of more sophisticated methods. Researchers routinely attach tiny transmitters to bats to track where they fly and roost; and even their temperatures. These transmitters emit pulses of radio waves that allow researchers to triangulate and track their positions, and new models of tracking devices are getting smaller and more advanced. The newest transmitters can communicate with satellites to reconstruct flight paths of long-range migrations, but these are still too large for most bats.

Photo by Gerald Carter

Photo courtesy Winifred Frick

Gerald Carter tracking bat movements by telemetry; Winifred Frick releasing a lesser long-nosed bat on Isla Carmen in the Sea of Cortez under a full moon. Right : Big-eared wooly bat *(Chrotopterus auritus)*, one of the largest predatory bats in the neotropics.

In an emerging field called "aeroecology," researchers are using advanced weather radar systems to track movements of both bats and their insect prey without the need to catch them. Researchers are now using data from Doppler radar systems to reconstruct three-dimensional models of millions of Mexican free-tailed bats emerging from caves in Texas, climbing high into the night sky, and consuming millions of migrating moths.

In light of the huge threat posed by wind farms, one of the most pressing questions in bat conservation is clear. Where and when do bats migrate? In the years to come, our knowledge of bat migration will undoubtedly take leaps forward, propelled by continuing advances in tracking technologies.

Bat movements can also be assessed indirectly in some rather ingenious ways. When animals eat, they acquire the atoms from their local environment into their bodies. Since the ratios of stable hydrogen isotopes change with latitude, the stable hydrogen isotope ratios of bat fur can reveal where bats have been traveling and eating. Similarly, since desert plants use different versions of photosynthesis (CAM photosynthesis and C3 carbon fixation), they can produce distinct carbon isotope ratios in their tissues. Researchers have used stable carbon isotope analysis to show that endangered lesser long-nosed bats

Photo by Angelina Menchaca

The sight of large numbers of bats flying in the twilight is always spectacular.

Photo © BCI

Little yellow-shouldered bats are important seed dispersers in tropical forests.

Photo by Marco Tschapka

rely heavily on agave plants on their migration south and on dense stands of columnar cacti on their way back north.

Stable isotopes are not the only kind of invisible clue available to researchers. Using tissue samples of lesser long-nosed bats caught in only 13 locations, researchers have also described genetic divergence between populations and migration routes by analyzing variation in DNA. The use of such genetic information in ecology studies has exploded in recent years, and what we are seeing is likely only the tip of the iceberg.

CLUES FROM GENES & GENOMES

The realization that huge amounts of ecological information can be obtained from DNA has led to the exploding field of molecular ecology, and in coming decades molecular tools will be increasingly important for bat ecologists. In fact, the fastest growing scientific technology today is DNA sequencing. Since the information for building an organism is written in the DNA code, sequencing fragments of DNA, or even the entire genome of an individual, has the potential to reveal all the biological information that makes an individual or species unique. Tracing changes in the genomes from one population of animals to another allows us to map exactly how they are related to each other on the family tree of all life. As the evolutionary history of bats becomes increasingly clear through molecular techniques, we will have a better understanding of how, why, and where bats evolved and how they are related to all other living things. Studies of gene flow and population genetics can help us identify the populations for which conservation is most critical.

Molecular techniques can also answer more basic ecological questions. For instance, we can use DNA to study kinship, family dynamics, and social lives of bats, or we can sequence the prey DNA in bat guano to see what bats eat. Sequencing the DNA of the pathogenic fungus *Geomyces destructans,* which causes White-Nose Syndrome, may help us understand where the fungus came from and what makes it so destructive to North American bat populations. The information in DNA is profoundly vast and will only be fully realized by future generations.

A genome is like a code for making an organism, but the information remains largely encrypted. Although we know the information is there, we are still not sure which parts of genomes are meaningful. But comparisons can give us information. By comparing genes and genomes, the evolution of similarities and differences among and within living species can be identified. In the future, we might be able to "read" genomes in the same way we read the blueprint for an invention. We might be able to predict much about the biology, ecology, even behavior of an unfamiliar organism simply by sequencing the DNA in a speck of tissue. This is the lofty goal of bioinformatics, possibly the fastest growing field of science. Bats have evolved into more than 1,200 species, and possess an extraordinary amount of genetic diversity even within a single species. The next few decades will allow us to explore how and why bats became so successful and speciose.

Whither the NATURAL HISTORY OF BATS?

Does this era of modern molecular biology spell doom for organismal biology? Today, natural history, the description of nature, is more likely to grace the pages of popular magazines than of leading scientific journals. Natural history developed into the science of organismal biology, including ornithology, ichthyology, mammalogy, and others. Compared to modern molecular genetics, these taxon-specific fields often seem to be in academic decline, receiving less science funding and less academic attention. Modern biologists have been increasingly turning their attention away from particular species toward genes and ecosystems. As one of my colleagues once put it, "DNA is DNA. I don't always know what the animals even look like." At the same time, the modern conservation movement has also been trending toward a focus on conserving ecosystems, rather than on protecting single species one at a time. This holistic approach is efficient because habitat destruction and anthropogenic changes at the ecosystem level are problems that threaten multiple species. From this perspective, one might wonder why we should even focus time and energy specifically on bats. It may seem that by simply protecting habitat, we will be protecting bats alongside other wildlife, and we might not need to know detailed ecological information about the lives of bats.

But this view is naïve. Knowing the natural history of bats is as indispensable as ever to their conservation. The problems of wind turbines and White-Nose Syndrome clearly make this point, because these threats endanger bats specifically. In order to confront such threats, we must possess intimate knowledge about behavior, ecology, and physiology unique to bats. And the bulk of this knowledge is simply lacking. When bat biologists first realized the gravity of the threat that wind turbines posed to migratory bats, we were all but embarrassed to admit to ourselves just how little we knew about bat migration or the

Photo by Marco Tschapka

Lesser long-nosed bats provide essential linkages to ensure sexual reproduction among many columnar cacti in the Sonoran Desert.

Photo © BCI

Lesser long-nosed bats also disperse the seeds of many columnar cacti.

Photo by Paul Berquist/ASDM digital library

The big brown bat consumes significant numbers of crop and forest pests.

Photoby Winifred Frick

Recent research indicates that some Baja populations of insectivorous pallid bats also take advantage of floral nectar.

population sizes of migratory bats. Where did different bats migrate? How many were there? How far did they go? What paths did they take? These and other basic questions must be addressed by researchers in the coming years. Similarly, white-nose syndrome was discovered as early as it was thanks to the work of bat biologists who actively monitored caves and mines where bats hibernate. There's simply no replacement for careful observations of the natural world.

One obvious lesson we can take from these recent threats to bat conservation is that organismal biology and species-specific natural history are *absolutely essential* for conservation. Only a few years ago, I would have written that the future of bat conservation in North America lies in protection of habitats and ecosystems. No one expected the White-Nose Syndrome population crash or the mortality effect of wind turbines. Few scientists or conservationists expected that detailed information about the immune systems or migration patterns of particular bat species would become so immediately and extraordinarily crucial to their conservation.

General conservation and ecology is not enough. We need to know more about the natural history of most of the North American bats. To save bats, we need people who call themselves bat biologists. Not all the most important questions can be solved quickly with the latest technologies; sometimes solutions are best acquired through years of rigorous fieldwork. Gathering important ecological data or observing natural behaviors often requires long days over continuous months in the field. But the experience is rewarding, and the results can be illuminating.

Ecological fieldwork is still crucial for determining what role bats play in a healthy ecosystem and how important bats are for producing the essential resources people derive from natural communities. For example, experiments on bat pollination have shown that bats are generally more effective pollinators of plants per visit than bees or birds. In fact, plants once pollinated by birds have more often evolved to become bat-pollinated than vice versa. However, in many areas, desert plants adapted for bat pollination now rely increasingly on suboptimal insect or bird pollinators simply because the bats have become too scarce. Other plants that are tightly coevolved with bats will not be able to adapt so quickly to the local loss of bat populations. The fate of bat pollinators and many of their desert plant allies are intertwined: a threat to one poses a threat to the other. Other recent ecological studies have shown the importance of bats in reducing insect pests (up to 84 percent in Mexican coffee plantations). In 2011, a report in the journal *Science* suggested that the insect-control services of bats were worth roughly $23 billion each year to agriculture. In most cases, the ecological importance of bats is vaguely known, but not well documented. Further ecological studies documenting the importance of bats will be vital to their conservation.

Given their huge diversity, great abundance, and wide-ranging distribution, as well as the critical roles they play in ecosystems and in our own well-being, bats will no doubt continue to be the focus of many scientists around the world. This particular field continues to grow and attract some of our brightest young minds. Many more questions remain than can be answered with the current workforce. Luckily, searching for the answers is exciting, and finding them holds promise for a better world for humans and for bats. S

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Photo by Rodrigo Medellin

The National Autonomous University of Mexico carries out research conservation in many areas of the country, including cave surveys. Here, a group of students under the direction of Dr. Medellin (lower left) monitor a Mexican free-tailed bat colony in Chiapas, Mexico.

Photo by Marco Tschapka

The flight of a Baja California fish-eating bat is observed in a flight cage.

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