WINGS

ESSAYS ON INVERTEBRATE CONSERVATION

THE XERCES SOCIETY FALL 2008

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Introduction

Scott Hoffman Black

Readers of *Wings* certainly know that there is an incredible diversity of invertebrates. When it comes to protecting them or their habitat, I imagine that many of our readers have been asked, "So, what do invertebrates do for me?"

This issue of *Wings* provides at least a partial answer to that question. Our first essay, "Small Animals That Pack a Big Punch," gives an overview of why invertebrates are so important for life on earth. Whether you are a salmon, a grizzly bear, a song bird, or a human, you rely on insects and other invertebrates for everything from food to waste clean-up. Although grasshoppers are often derided as pests, "Grasshoppers: Nuisance or Necessity?" details how these insects are vital for the functioning of prairie ecosystems. The importance of freshwater mussels—and their fascinating relationship with fish—is discussed in "Overlooked Gems: The Benefits of Freshwater Mussels." Pollinators are vital for both the production of food and wild plants. The essay "A Global Perspective on Crop Pollination" illustrates how farmers throughout the world rely on insects for production of their crops. The last essay, "Dirty Work, Done Dirt Cheap," is about the not-so-lowly dung beetles, amazing creatures responsible for processing animal waste that would otherwise build up to unhygienic (and frankly, alarming) levels.

We hope this issue gives you a renewed appreciation for the little things that keep the world running.

The activities of insects and other invertebrates sustain the health of our environment and provide a foundation on which humans and wildlife rely. Leafcutter ants (*Atta cephalotes*), photographed in Trinidad and Tobago by Bryan E. Reynolds.

Small Animals That Pack a Big Punch

Scott Hoffman Black and Matthew Shepherd

Each summer, millions of moths migrate from the dry, western margin of the Great Plains up to steep slopes above the timberline of the Rocky Mountains. Miller moths (*Euxoa auxiliaris*), also known as army cutworms, begin and end their life cycle in fields and gardens on the plains. During the dry season, they spend a couple of months in the mountains, probably because the high-altitude flora offer a reliable seasonal source of nectar. Here, the moths shelter from the sun under rocks and logs during the day, emerging at night to feed.

To people living along the migration route these moths can be a pest, but grizzly bears love them, and the moths are a key component of their annual diet. Indeed, the massive concentration of moths draws large numbers of grizzlies to the mountain tops for a month or longer. A single grizzly may consume ten to twenty thousand moths a day, which over the period of a month can amount to three hundred thousand calories worth of fat-rich nutrition, more than a quarter of the bear's annual calorie intake. This period of gluttony is vital in preparing the bears for hibernation, particularly for pregnant females because cub survival is greatly influenced by a mother's pre-hibernation diet.

The miller moth (*Euxoa auxiliaris*) migrates each summer high into the Rocky Mountains, where it becomes a key food source for grizzly bears. Photograph by Whitney Cranshaw.

Only one other food event causes more grizzlies to gather in North America and that is the salmon returning to their spawning streams in the Pacific Northwest. Although the grizzlies may not be consuming moths, as they feed on salmon they are no less reliant on insects: the food that fueled the young salmon years before on their outward trip to the ocean was composed largely of the aquatic larvae of midges.

These are just two of the innumerable ways that invertebrates sustain our environment, whether by serving as food for other wildlife or by providing another ecosystem service such as pollination or waste disposal. The sheer abundance of invertebrate species—and of individual invertebrates themselves—means that they are present in virtually every corner of our planet, from pole to pole and from the deepest ocean to

Directly or indirectly, grizzly bears across North America rely on invertebrates for food. Photograph by Dawn Nichols.

the highest mountain. Measured by the number of formally described species, insects are by far the most diverse group of organisms on Earth. In excess of 950,000 species of insects have been described, comprising over 70 percent of the total identified animal species. (Other invertebrates make up another 15 to 20 percent of species.)

Even more remarkable are the estimates of how many insects we have not catalogued. Most insect species that have been classified and named to date are from temperate zones, but tropical habitats harbor far more. Smithsonian Institution entomologist Terry Erwin has suggested that as many as thirty million insect species may exist. The most conservative estimates suggest that between five and eight million insect species have not been discovered. This number contrasts sharply with the five to ten thousand species of vertebrates that may await discovery and description around the world.

Insects dominate in terms of mass as well. Although tiny individually, together they are literally the heavyweights of the planet. Some scientists estimate that insects and other arthropods comprise more than 85 percent of the total weight of all land animals. If you weighed all of the animals in an acre (two-fifths of a hectare) of tropical rainforest, around a third of the weight would come from ants and termites alone.

But what do such numbers tell us about the importance of insects? Quite a bit, actually. The huge diversity of insects means that they fill many ecological niches and thus play a role in the func-

The northern flicker (*Colaptes auratus*) is regularly seen feeding on ants on the ground in gardens and parks. Photograph by Steve Jennings.

tioning of many different communities. In fact, there are very few terrestrial environments where insects are absent.

Admittedly, some insects have a negative impact on humans, either by harming us directly through bites, stings, and the spreading of disease, or indirectly by attacking food crops, tree plantations, and livestock. Even so, all adverse effects combined are insignificant compared to the beneficial activities of insects. Insects are a part of nearly every food web, either as food for other animals or as agents in the endless recycling of nutrients in the soil.

Nearly nine out of ten bird species feed on insects and other invertebrates at some point in their life cycle, with martins and swallows among the most obvious, along with songbirds and woodpeckers. (The northern flicker, for example, eats more ants than any other bird in North America.) Game birds from sage grouse to bobwhite quail also rely on insects, and many birds of prey feed on insects, particularly as food for their young.

Insects are also important as consumers, not just as the consumed. In particular, insect herbivores can have a tremendous impact on plant communities. Grasshoppers contribute significantly to grassland function, and as a group they may have been as important as the American bison in converting grass back into nutrients. In conifer forests, bark beetles and defoliating insects fill a key role by recycling nutrients. Although some of these herbivores are considered "pests," they are vitally important to the sustainability of these ecosystems.

Some insect consumers eat a range of things that we find noxious and disgusting—animal dung and carcasses, to name but two—and consequently play an essential role in waste disposal as well as nutrient recycling. The first animals on the scene when a vertebrate dies are often flies (followed by a series of beetles, even moths), and dung beetles are vital to the decomposition of animal waste. Without them we would be up to our necks in waste and dead animals and plants.

On a more pleasant note, insects, particularly bees, pollinate most human food crops as well as most other plant species. The ecological service insect pollinators provide is necessary for the reproduction of about 70 percent of the world's flowering plants. This includes more than two-thirds of the world's crop species, whose fruits and seeds together provide more than 30 percent of the foods and beverages that we consume.

The spheres of business and technology, particularly medicine, have benefited from insects. The common fruit fly (*Drosophila melanogaster*), generally considered a pest in kitchens worldwide, has been at the center of genetics research for a century, enabling advances in the understanding and treatment of several human diseases. Recent studies of another group of *Drosophila*, the highly endangered picture-wing flies of Hawaii, indicate that they possess auto-immune system characteristics previously unknown to medical science. At a more basic level, disinfected maggots are used to debride wounds. The benefits of insect studies extend well beyond medicine: elucidation of the way that ants in a colony coordinate their interactions led to breakthroughs in the management of shipping terminals. What other discoveries await us?

During debates about conserving or protecting at-risk species, the question "What good are insects?" frequently arises. When insects are widely perceived as pests and nothing more, it may be difficult for people to grasp why they should receive legal protection. But the services of rare and endangered in-

Endangered everywhere it lives, the American burying beetle (*Nicrophorus americanus*) buries carcasses on which to rear its young. Photograph by Doug Backlund.

sect species can be every bit as vital as those of common species. Ecosystem functions, such as the recycling of nutrients, often are done by insects with a particular skill, such as the American burying beetle (*Nicrophorus americanus*), federally listed as endangered.

Rare species also can act as keystone species in small, specialized systems, such as caves and oceanic islands, or in some pollinator–plant relationships. For example, a plant on the federal list of endangered species, the dwarf bearclaw poppy (*Arctomecon humilis*), which grows in the desert areas of Utah, relies primarily on a single species of bee for pollination—and the bee, *Perdita meconis*, is itself uncommon.

Invertebrates can be used as indicator species to monitor the environment. The presence or absence of caddisfly and mayfly larvae helps with the assessment of creek health. Butterflies can be used to determine the condition of meadow and prairie habitats, and snails can be used to judge the vitality of old-growth forests. Like a canary in a coal mine, uncommon or rare insects offer a sensitive method for judging the health of their, and our, environment. Protecting habitat based on these small animals also protects habitat for other more charismatic species.

There are countless ways in which humans depend on insects for essential services. Putting a dollar value on these services is not easy, but in a recent paper in the journal *Bioscience*, John Losey of Cornell University and Mace Vaughan of the Xerces Society estimated that the services of insects are worth more than $57 billion per year to the U.S. economy. Their study showed that insects are a critical food source for the animals that drive a $50-billion-per-year recreation industry. If you enjoy bird watching, fishing, or hunting game birds, you can thank insects for the opportunity. Pollination by wild insects, primarily native bees, boosts farm harvests by $3 billion annually. (If you include managed honey bees this number goes up to $20 billion.) Native insects that control pests save growers an estimated $4.5 billion per year, and the dung beetles that help clean up grazing lands save ranchers more than $380 million.

From grizzly bears to the bearclaw poppy and beyond, we all rely upon insects and other invertebrates. In this article, we have only touched briefly on a limited selection of the fundamental, yet frequently unseen, roles in which they frame our lives. According to E. O. Wilson, Pulitzer-Prize-winning author and renowned scientist, “So important are insects and other land-dwelling arthropods that if all were to disappear, humanity probably could not last more than a few months.” This sentiment has been echoed by many other authors, scientists, and commentators, and yet insects are frequently dismissed as pests to be controlled, creatures that can be painlessly removed from our lives. The reality is that they can’t be, and if they were, we would all be in deep trouble. As Tom Eisner, former president of the Xerces Society, so eloquently put it, “Bugs are not going to inherit the earth. They own it now. So we might as well make peace with the landlord.”

The authors both work for the Xerces Society. Scott Black is executive director and Matthew Shepherd is senior conservation associate.

Grasshoppers: Nuisance or Necessity?

Dan Johnson

Grasshoppers. There are few insects that so frequently find themselves in a sentence with the word “plague.” Negative views of grasshoppers are widely held and often deeply entrenched, far better known and accepted than the wonder of their range of natural activities and diversity. It appears that the emotional component of attitudes toward invertebrates may be difficult to change, because it is the product of more than a simple lack of knowledge.

With Jennifer Mather, a fellow invertebrate researcher at the University of Lethbridge in Alberta, Canada, I surveyed the attitudes and knowledge of nine hundred Lethbridge undergraduate students toward invertebrates. The students completed a survey of questions that addressed three types of attitudes: cognitive (thinking and factual knowledge), moral (including ethics and valuing), and affective (feeling, including what we might call gut feeling).

After a lecture that included photographs and lore regarding the lives and diversity of five kinds of invertebrates (earthworm, crab, grasshopper, octopus, and spider), we re-surveyed the students. The results showed shifts in cognitive and moral attitudes, but very little change in the affective attitudes. The change in feelings for grasshoppers, for example, was approximately zero. This may not be a surprise, considering how widespread is the perception of grasshoppers as a nuisance. The results also reflect the way that human

In prairies, grasshoppers are central to both vegetation recycling and as food for other wildlife. Green-striped grasshopper (genus *Chortophaga*), photographed by Bryan E. Reynolds.

encounters with just a few species can color attitudes about all grasshoppers.

Of the hundreds of species of grasshoppers that live in the grassland, woodland, and cropland of North America, only a small proportion actually are pests—and then only under certain conditions. Of the nearly one hundred grasshopper species found in the Canadian Prairies, a mere six have the potential to cause serious damage to crops or impact livestock grazing. Because other species prefer—or in some cases are entirely restricted to—plants that are considered serious weeds, they are seen to be more directly beneficial. Turnbull's grasshopper (*Aeoloplides turnbulli*) is one such example; it is also called the Russian thistle grasshopper because of its preference for this plant (in the genus *Salsola*, and known as tumbleweed) and other weedy members of the family Chenopodiaceae.

Most grasshopper species have no direct economic impact but play a central role in the food webs of grassland. Herbivory by grasshoppers is a natural part of the operation of ecosystems, assisting in the flow of energy and cycling of nutrients. Dead plants take a long time to decay and return their nutrients to the soil, but both the plant clippings dropped by feeding grasshoppers and the grasshoppers' fecal pellets are quickly degraded, aiding the rapid recycling of nutrients. The grasshoppers themselves also are important as food items for predators as diverse as robber flies, spiders, birds, and coyotes, another way in which plant energy is recycled in the ecosystem. The ecological significance of grasshoppers and other arthropods was underscored by the Matador Project, a total ecosystem study conducted in Canada between 1968 and 1972. Researchers analyzed the structure and functioning of a grassland ecosystem, particularly monitoring the productivity of the grassland and the flow of energy through the ecosystem. The study found that the total energy value of above-ground invertebrates was a hundred times that of the birds, and six hundred times that of the mammals—proof indeed that the obvious animals are not necessarily the most important.

Research conducted in the prairies of Alberta in the early 1990s illustrates the importance of grasshoppers—spring species in particular—in the grassland ecosystem. It also demonstrates the value of biodiversity for stability in the food web. The main objective of the research was to determine the food resources of migratory grassland songbirds, particularly the chestnut-collared longspur (*Calcarius ornatus*), the dominant grassland songbird in the area. A second objective was to determine how the birds' diet and survival could be affected by removal of grasshoppers due to pest-management actions. Collaborators included two Canadian Wildlife Service scientists (avian ecologist Pam Martin, and Douglas Forsyth, studying small mammals), pesticide chemist Bernie Hill, and me.

In the first year of the study, by monitoring food items fed to chicks in their nests, we determined that more than 70 percent of the diet provided by longspurs to their nestlings was grasshoppers—and for the early broods in April and May most of the grasshoppers belonged to one species, the brown-spotted rangeland grasshopper (*Psoloessa delicatula*). This species is unusual

The club-horned grasshopper (*Aeropedellus clavatus*) hatches unusually early in the year, and thus is an important food item for spring-nesting birds. Photograph by Dan Johnson.

because it overwinters as a mid-size immature and matures early in the spring—most species overwinter as eggs buried in the soil—and this means that it is available as longspur food much earlier than other grasshoppers.

In the second year of our field work, we again found that grasshoppers were the dominant food item for the early broods, even though inclement fall and spring weather had resulted in very low populations of the brown-spotted rangeland grasshopper. It was replaced in the diet by another early-spring species, the club-horned grasshopper (*Aeropedellus clavatus*). Unlike the brown-spotted rangeland grasshopper, the club-horned grasshopper overwinters in the egg stage, but it has unusual physiological adaptations that allow it to grow at very low temperatures, and thus hatch weeks or months before other species. The diversity of species and life-cycle types meant that one or the other of these grasshoppers was available to be the major food supply of the longspurs, enhancing the sustainability of the songbird populations.

The population dynamics of most grasshoppers in grassland ecosystems are strongly influenced by weather, and by other biota such as predators and diseases. The resulting population swings in relative and absolute abundance can strongly influence vegetation and the predators that feed on grasshoppers. Some endangered vertebrate species are known to be strongly affected by these swings in food supply. Juvenile burrowing owls (*Athene cunicularia*) are fed small mammals by their parents, but when they leave their burrows they capture large numbers of insects. These include the red-shanked grasshopper (*Xanthippus corallipes latefasciatus*), which is not only one of the largest grasshoppers in North America, but also one of the earliest found in the spring. It overwinters as a nymph—so fat and bumpy that it resembles a small toad—and is active in April and May, feeding on vegetation, such as Sand-

The red-shanked grasshopper (*Xanthippus corallipes*) is one of the largest grasshoppers in North America. It overwinters as a nymph, shown here. Photograph by Dan Johnson.

berg bluegrass (*Poa secunda*), that begins growth very early in the spring.

Early emergence has its risks. Cool, moist spring conditions reduce survival and growth, and the red-shanked grasshopper can be nearly absent in years with such weather. After many years spent monitoring burrowing owl reproduction, researchers Ray Poulin and Danielle Todd are convinced that a low rate of fledgling survival is related to the collapse of spring grasshopper populations because poor owl nesting success in most years is attributable to a lack of food, and grasshoppers are one of the key food sources.

There are times when the role of grasshoppers as bird food can have unexpected negative impacts. In recent years diverse species of Orthoptera, including the clear-winged grasshopper (*Camnula pellucida*) and broad-winged bush katydid (*Scudderia pistillata*), have experienced significant increases in abundance in Canada. These increases in population have become a hazard to airplanes, since the opportunity for a meal of katydids and grasshoppers attracts flocks of gulls and other large birds to the grass next to runways. The katydid was previously rare and difficult to find on the Canadian Prairies, but since 2001 its numbers have increased across the grasslands and northward to the boreal forest. The reason for this is not clear but is likely related to changing weather patterns.

The long evolutionary relationship of grasshoppers and birds has resulted in apparent adaptations of grasshoppers to reduce predation. One striking case is the sagebrush grasshopper (*Melanoplus bowditchi canus*), which feeds on silver sagebrush, *Artemisia cana*. It is often found at rest on the sagebrush, where the silver-gray color of the top of the grasshopper's body (along the head, pronotum, and tegmina, the forewings that cover the hindwings) helps it hide from avian predators. While searching for this and several other sage specialist grasshopper species in the Big Muddy area of Saskatchewan, I was surprised to see that, when approached, it behaves somewhat like a dry sage leaf flicking off the plant. It goes even farther in this strategy, and will often lie still after jumping. (Other spur-throated grasshoppers are known for their frantic jumping and flight under threat.)

Not all grasshoppers are concealed by cryptic coloration. A bright blue and yellow form of the red-legged grasshopper (*Melanoplus femurrubrum*) is found in isolated locations across the Prairies. The reason for this rare coloration is a mystery.

Despite their high ecological value, grasshoppers are often viewed with some distrust, even disdain, as demonstrated by the survey of Lethbridge students. There are, however, signs of changing attitudes. After seeing the results of the study on the importance of grasshoppers in the diet of chestnut-collared longspurs, I began a campaign to get people to leave the brown-spotted rangeland grasshopper (and other early-season species) alone. It began with a paper presented to the Entomological Society of Canada calling for special conservation of this important food item; and I mention the case whenever speaking to many grower groups, if only to save unwarranted and costly control actions. Although these species have no legal protection, there is now a greater awareness of the value of distinguishing different types of grasshoppers.

One spring not so long ago, when I was working at a pasture field study, a rancher stopped his pickup and told me not to worry about the grasshoppers seen flying in May. He'd heard on the radio that they don't cause problems. This growing acceptance within the farming and ranching communities that grasshoppers are not all a threat gives encouragement for a future in which grasshoppers are valued for their ecological contributions and not seen as pests to be controlled.

The sagebrush grasshopper (*Melanoplus bowditchi canus*) closely resembles sagebrush in both color and movements. Photograph by Dan Johnson.

A professor of environmental science at the University of Lethbridge and former president of the Entomological Society of Canada, Dan Johnson is recognized globally for his work on the ecology and control of grasshoppers. He is Canada Research Chair in sustainable grassland ecosystems, and organized the most recent world meeting on grasshoppers and locusts.

Overlooked Gems: The Benefits of Freshwater Mussels

Al Smith and Sarina Jepsen

Monkeyface, sheepnose, cat's paw, elk toe, pocketbook, pearlshell, pistolgrip, washboard, spectaclecase: freshwater mussels may have some of the most colorful common names of any group of animals, reflecting the fact that they have been part of the human experience for millennia. These wonderfully descriptive names were given by people seeking to differentiate among species while collecting and using them.

Archeological records show that Native Americans have harvested mussels for at least ten thousand years. Their soft bodies were eaten, and their hard shells were used as spoons and hoes, crushed as temper to strengthen clay when firing pottery, and made into jewelry. The pearls created by some species of freshwater mussels were often strung into necklaces or used decoratively, inlaid as eyes into animal designs.

Native Americans were not the only ones who were attracted to these gems. During the second half of the nineteenth century, pearl hunting became a big business, sparked in 1857 by the discovery in New Jersey of a pearl that

A shell midden left by a feeding animal, probably a raccoon, illustrates both the diversity and beauty of freshwater mussels. Photographed in Missouri on the Pomme de Terre River by M. C. Barnhart.

sold for $2,500—in excess of $50,000 today! The ensuing clamor for pearls was so intense that entire streams were stripped of their mussels.

To this day, the harvesting of mussels threatens some populations in the southeastern United States. Freshwater mussels remain in demand by the pearl industry, though not for their own pearls but for their shells. Pieces of the thick mussel shells are cut and placed inside marine oysters as seeds to stimulate the formation of oyster pearls. As important as this market has been, however, the greatest mussel-based industry was the manufacture of "pearl" buttons. Johann Boepple pioneered the craft, opening his first factory in Muscatine, Iowa, in 1891. Stamped out of mussel shells, the best buttons came from thick-shelled species such as the yellow sandshell (*Lampsilis teres*) and pistolgrip (*Tritogonia verrucosa*). At the time, there appeared to be an endless supply of these shiny, durable shells, and Boepple's success inspired others to join the industry. According to the University of Tennessee's Frank H. McClung Museum, by 1912 there were nearly two hundred button factories in the United States. Mussels remained at the heart of the industry until the 1940s, when they were replaced by plastics.

The freshwater mussels on which this great enterprise was based are unassuming creatures, not at all flashy on the outside. Ranging in size from one to ten inches across, mussel shells come in a variety of shapes, and they may be covered in all manner of lumps and bumps, ridges and furrows. They often are camouflaged against the rock or mud bottoms of streams and lakes, which might explain why these animals tend to go unnoticed, even by aquatic biologists.

When feeding, mussels open their shells to filter algae and bacteria from the water. Western pearlshell (*Margaritifera falcata*), photographed by Marie Fernandez.

The United States is home to almost three hundred species of freshwater mussels, more than 35 percent of the world's eight-hundred-plus species. They are found in streams, rivers, and lakes across North America but are concentrated in the southeastern states, a region that is considered a global hotspot for freshwater mussels. Alabama, for example, has 180 species, more than a fifth of the world's diversity.

Freshwater mussels are filter feeders that consume detritus, bacteria, algae, and diatoms. It is this habit that makes them more valuable alive than dead (processed into buttons or pearls), for as they feed they clean huge quantities of water. An individual mussel can filter more than eighteen U. S. gallons (seven-

Packets of larval mussels (conglutinates) can look remarkably like small fish, tempting larger predators to bite. Rainbow darter below conglutinates of Ouachita kidneyshell (*Ptychobranchus occidentalis*), photographed by M. C. Barnhart.

ty liters) of water per day. Mussels often live en masse in dense beds, together filtering sufficient water to purify the rivers and streams they inhabit. This is a key ecosystem service that maintains good water quality and supports the teeming life of a healthy waterway.

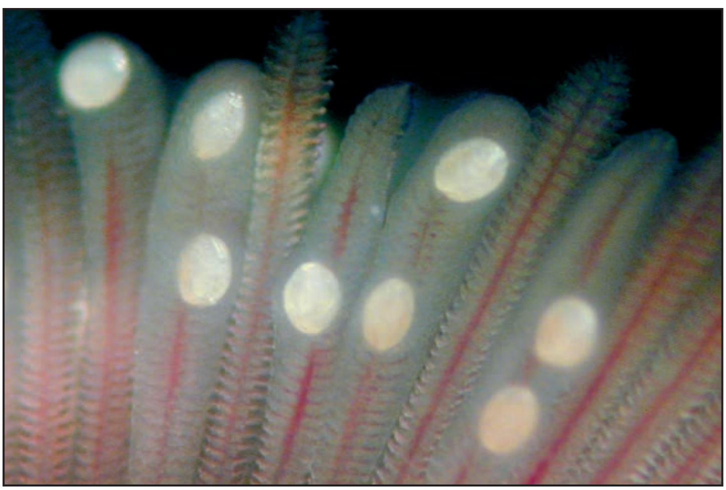
Interestingly, fish are integral to the mussels' ability to provide such ecosystem services. An adult mussel can pull itself small distances across a stream or lake bed using its muscular foot, but it is essentially a sedentary creature. To overcome this lack of mobility and enable them to move up and down stream courses, larval mussels, called glochidia, attach themselves to the gills or fins of a fish. After a few weeks of development on the host fish's body, young mussels drop to the bottom of a stream or lake, where they remain buried in the substrate and continue to grow larger. By hitching a ride on fish, young freshwater mussels are able to recolonize disturbed areas and pioneer new realms of favorable habitat.

Adult mussels have evolved creative methods to entice fish to become glochidial hosts; the orange-nacre mucket (*Lampsilis perovalis*), for example, produces conglutinates (packets of glochidia) that resemble small fish swimming in the current. When a fish is duped into biting one of these pseudo-fish, the conglutinate breaks up and individual glochidia attach to the fish. Other mussel species have evolved conglutinates that mimic worms, or even crayfish, to fool a fish into biting them and becoming a glochidial host. Although mussels have a parasitic relationship with fish in the early stage of their lives, as adults they repay the fish many times over for their service by filtering and cleaning water. Working in the Varzuga River on the Kola Peninsula in northern Russia, ichthyologist Valery Ziuganov found that visibility near a dense mussel bed was twenty times greater than it was in water away from the bed. Clearer water allows for deeper light penetration, which increases algal growth; algae make up the base of the aquatic food chain and are consumed by aquatic invertebrates, which comprise a large part of the diet of juvenile salmon and other fish. Additionally, clear water allows juvenile salmon and other fish to more easily find their invertebrate prey.

Ziuganov's research led him to conclude that stocks of Atlantic salmon (*Salmo salar*) were robust in part because large populations of the freshwater pearl mussel *Margaritifera margaritifera* (known as the eastern pearlshell in North America) maintained good water quality. He wrote: "Thus, pearl mussels and salmonids form an important symbiotic community in which each species finds optimal conditions for survival. The protection and restoration of these valuable species is therefore interdependent, and the conservation of either one will benefit both."

The benefits from mussels are not limited to their feeding. Many of the food items that mussels filter from the water are processed into packets of material (called pseudofeces) and discharged back into the water. These food packets provide nutrients for algae and detritus-feeding invertebrates. Living and dead mussel shells also provide a substrate for algae and invertebrates to colonize. Overall, these benefits to the lower links of the food web are advantageous to fish and by extension to the humans, birds, and other animals that consume fish.

Because native fish and freshwater



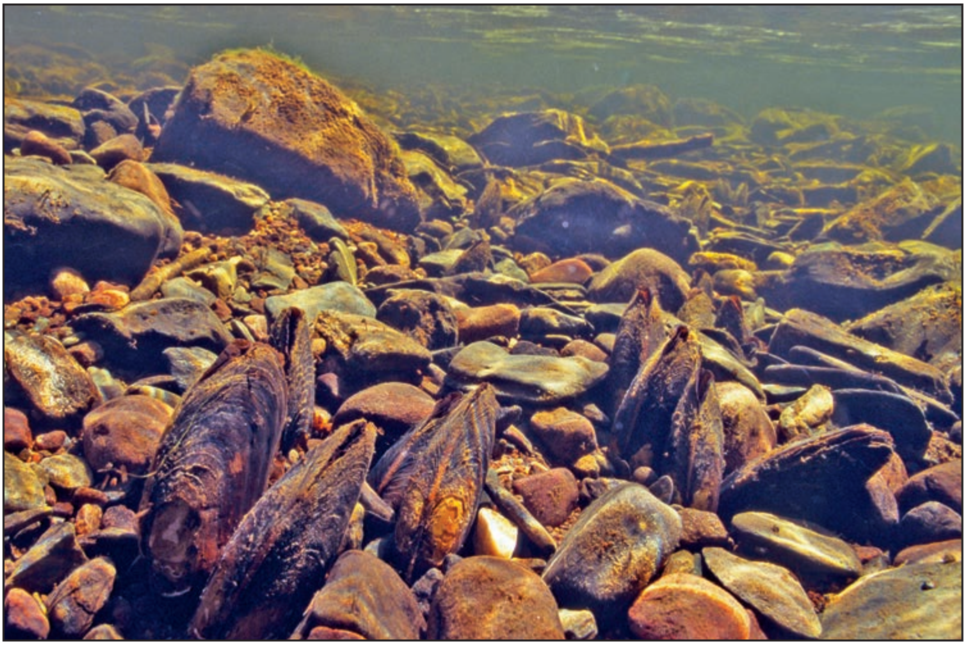
Once a fish has bitten the mussel's lure, the individual larval mussels attach themselves to the gills of the fish, as shown here. This enables the mussels to disperse and does not harm the host fish. Photograph by M. C. Barnhart.

mussels are intimately linked, declines in native fish populations present a major threat to the survival of freshwater mussels. Mussels are sensitive to environmental changes, which makes them excellent biological indicators of water quality. Many mussels are long-lived—with lifespans greater than one hundred years for the eastern and western pearlshells (*Margaritifera margaritifera* and *M. falcata*, respectively)—and the adults are sedentary. Studying these animals can help us understand how environmental changes affect aquatic ecosystems. The age structure of mussel populations can be determined by examining the growth rings on individual mussel shells, much as the age of a downed tree is revealed by the rings in its stump.

Different species of mussels each have their own method to attract host fish for their larvae. The pistolgrip (*Tritogonia verrucosa*) displays a mantle holding larval mussels. Photograph by M. C. Barnhart.

Dead mussel shells tend to persist in the environment and can act as historical archives to elucidate long-term environmental changes. Dr. Cynthia Tait, while working for the Bureau of Land Management in southeastern Oregon, compared the species composition of freshwater mussels in archeological Native American middens from parts of the Owyhee River basin to the current mussel species composition in those same areas. Her study revealed that the western pearlshell has disappeared from some areas where it historically occurred, perhaps due to the loss of native fishes such as Chinook salmon (*Oncorhynchus tshawytscha*) and redband trout (a subspecies of *Oncorhynchus mykiss*) and high sediment loads in some reaches. The installation of dams along the Owyhee River over the past century obstructed the passage of anadromous native fish (which live in the ocean and breed in fresh water) and likely contributed to local extirpations of the western pearlshell.

Unfortunately, the great benefits that mussels provide to both natural ecosystems and to humans may be in jeopardy. Freshwater mussels are the most at-risk group of animals in North America; 69 percent of all species of North American freshwater mussels are considered to be vulnerable, imperiled, or extinct. Although scientists, conservationists, and biologists have worked to understand and protect mussels in the Southeast, much less is known about species west of the Rocky Mountains. While there is a paucity of information on the biology and status of western freshwater mussels, anecdotal evidence suggests that these animals are experiencing the same population declines



The range of the freshwater pearl mussel (*Margaritifera margaritifera*) extends from Russia through Europe and into North America, where it is called the eastern pearlshell. Everywhere it is found, the mussel plays an important role in maintaining clear water. Photograph by Sue Scott, courtesy of Scottish Natural Heritage.

that eastern species have experienced. The Xerces Society, in collaboration with members of the Pacific Northwest Native Freshwater Mussel Workgroup, is beginning a status review to understand the current and historical distribution of the three genera of western freshwater mussels that once ranged from Alaska south to Baja California and as far east as New Mexico and Montana.

A few years ago while in the small town of Merrill in south-central Oregon, Al Smith stopped at a bridge and saw a large plank floating in the river below. On the plank, which had no doubt served as a convenient dining platform for a river otter, were the shells of four Oregon floater mussels (*Anodonta oregonensis*), a reminder of the various roles that freshwater mussels play in aquatic food webs, and of the many reasons it is vital to work to conserve them.

Al Smith became interested in the plight of freshwater mussels in the Pacific Northwest after a career as a fish biologist. He co-founded the Pacific Northwest Native Freshwater Mussel Workgroup, and has done field surveys for mussels in five western states, co-authored a field guide to Northwest mussels, taught college short courses, and given or set up numerous other presentations on mussels.

Sarina Jepsen is the endangered species coordinator at the Xerces Society and current chair of the Pacific Northwest Native Freshwater Mussel Workgroup.

A Global Perspective on Crop Pollination

Margie Mayfield

Crop pollination is one of the most widely known ecosystem services. The issue that has received the greatest media coverage in recent years is the decline of the European honey bee, particularly in America; but a different perspective on this ecosystem service emerges from an examination of pollination on farms in several developing nations. The difficulties faced by farmers reliant on insect pollination for crop production are heavily tied into the socio-economic status of the farmer and the educational and political details of the community where a farmer lives; yet we rarely hear about the diversity of issues relating to crop pollination in most of the world's agricultural communities.

My study of crop pollination began about ten years ago with a fellowship from the Thomas J. Watson Foundation that enabled me to spend a year travelling to study the ways that socio-economics and culture influence farmers' understanding of the importance of wild insects to crop pollination. As an environmentally minded young person just out of college, I set out with an optimistic (and perhaps arrogant) sense of what I would find in Bolivia, South Africa, Malaysia, New Zealand, and India. I soon discovered that my world view was quite naïve, as was my understanding of the farming communities in those countries.

At the outset, I believed that, because of their historical connection to the natural world, most of the poor farmers I was hoping to meet would have more knowledge than Western farmers do of how to farm sustainably. I expected people's appreciation for and knowledge of the natural world to be more influential than poverty, politics, and modern circumstances in defining the farming practices they used. I learned very quickly that this view was not only incorrect, but dismissive of the fact that these people grapple with a rapidly changing modern world just as everyone else does.

In general, I found that many indigenous farmers relied on knowledge passed down for generations, knowledge that had been developed at a time when there were far fewer people farming in a given area and when chemicals were not an option for increasing yields. In much of the world, services such as pollination have started to decline only in the last twenty or thirty years. Because historically pollination was a naturally occurring service, abundant and free, many of the people in the poor farming communities I visited knew nothing about it, nor did they realize that this service could change or cease. In most of these communities farmers were very interested in modernizing their farms. The benefits of using modern farming techniques seemed obvious—farmers using modern techniques earned more money from their land—and almost no one foresaw any downsides to switching to modern practices. For the majority of farmers, the only thing stopping them from abandoning their less-intensive traditional farming practices was a lack of finances, not a love of nature or a desire to farm sustainably.

In Bolivia, I stayed at the farm of a wealthy landowner in the Andean foothills several hours outside of La Paz. At one time, this family had owned and farmed much of the region, but they had lost most of their property to land reforms during the previous fifty years. The other inhabitants of this valley were of Aymara heritage. The Aymara people have lived in Andean Bolivia for at least two thousand years but were serfs first of the Incas and then of the Spanish, and it was not until the late twentieth century that most of them had the freedom to farm their own land. While these Aymara are indigenous to this region of Bolivia and have a long farming history, they now grow many non-traditional vegetable crops, as well as crops such as coffee that have high export value.

I expected to see very specialized farming techniques developed over hundreds of years. The farmers growing coca for tea and chewing (not for the production of cocaine) did have highly developed and fairly traditional farming techniques, but most of the other farmers did not. The majority grew their crops using methods that were neither particularly steeped in history nor intentionally environmentally friendly. With almost no money to develop or maintain their fields, most were doing whatever they could to get by. There were a few wealthier Aymara farmers who were, on a small scale, using "Western" industrialized farming techniques,

The role of crop-pollinating insects is not widely understood in Bolivia. Some farmers thought that bees sapped energy from their crops. Stingless bees (genus *Trigona*), photographed on squash flower by Margie Mayfield.

but most could not afford to buy the chemicals and equipment necessary to modernize.

From a crop-pollination perspective, I also found—regardless of the farmers' wealth or farming success—an almost uniform lack of understanding on their part of the pollination role played by insects and of the significance of insect pollination to most of their crops. Several farmers indicated that they thought bees and other insects were unimportant for their crops, neither harmful nor helpful, and others thought the pollinators actually had a negative effect, sapping energy from their plants. Of the farmers that I interviewed, only one (who did not have a Western education) had an extensive and correct understanding of what pollination is and the importance of it to his crop yields. He said that a few years before there was a season with almost no pollinators and everyone had had a very unproductive year, and he was worried that it was probably just the beginning of a longer-term problem. I suspected that he was right.

Despite a lack of funds to modernize, the drive to increase quality of life and thus crop production in this and similar communities is leading to a steady intensification of agricultural practices—a bad trend for pollinators. When I was visiting this community a decade ago, there was only one patch of rainforest remaining in a series of three mountain valleys. The rest of the land had been cleared for agriculture. Deforestation has been shown to lead to declines in native pollinator numbers in many systems, but even with such extensive deforestation, there were a surprising number of pollinators still in the area, probably due to the low-intensity practices of most farmers. Back then, tilling for weed control and the application of chemical herbicides and pesticides were still uncommon.

It was somewhat discouraging to find that, while many Aymara farmers were interested in studying agriculture in order to make informed decisions about how to modernize, there was almost no opportunity for them to gain information about high-yielding sustainable and pollinator-friendly agricultural practices. The only information about how to farm was coming from sellers of chemical herbicides, pesticides, and fertilizers.

The lack of educational opportunities in this Bolivian community was in stark contrast to what I found in the southern Indian states of Kerala and Karnataka. Here the Indian government was aware that poor and indigenous farmers were using practices that were no longer ideal for the sustainability of their land and the maximization of their yields. As in Bolivia, the ancestors of these people had probably been farming for thousands of years. They too had developed farming practices at a time when there were many fewer people and many fewer pressures to sustain the agricultural value of any individual plot of land.

These farmers grow a variety of crops but the most common were cardamom and coffee, both of which are bee-pollinated. Our common European honey bee (*Apis mellifera*) does not do well in southern India, and the main pollinators of cardamom and coffee in southern India are two native species of honey bee, the giant honey bee (*Apis dorsata*) and the Asiatic honey bee (*Apis* *cerana*). Efforts to domesticate these species have mostly failed for the giant honey bee although they have succeeded to some extent for the Asiatic honey bee, but because these species are not easily domesticated, most farmers in southern India rely entirely on wild bee populations.

These populations, though, have been in decline for the past twenty years, attributable both to habitat loss and to increasing pressure from native honey collectors. Honey collecting from the giant honey bee is a centuries-old tradition in the region, but traditional honey-collecting techniques involve the total destruction of the hives. Historically this practice was sustainable because there were few honey collectors and many hives; today, that ratio is being reversed, and these bees are disappearing from many agricultural landscapes. Declining bee numbers mean that keeping bees on a farm year-round is important for ensuring that they will be there for the next crop blooming season.

In recent years the Indian government has taken some active steps toward solving the growing pollinator problem in southern India. The Indian Council of Agricultural Research, the Ministry of Rural Development, and the Indian Spice Board all have started educational programs that teach farmers why bees are important (emphasizing pollination over honey production), how to maintain the Asiatic honey bee in managed hives, and how to retain wild pollinator populations in crop fields.

One very successful practice that is currently being tested is the use of shade trees that form a "floral calendar." Floral calendars are lists of bee-pollinated tree species that bloom at different times of the year. Because cardamom and coffee require shade and are often grown with black pepper, a vine that needs trees to grow on, trees are a necessary part of these plantations. By selecting a diversity of trees that bloom at different times of year, farmers can ensure that floral resources are available for wild bees year-round. This encourages bee colonies to stay in plantations and thus be there for the crops' blooming season. This proactive, education-based approach to protecting pollination as an ecosystem service in areas dominated by subsistence farmers results in increased yields while promoting a sustainable mode of farming. This approach also recognizes that, regardless of a people's history, the world is a changing place and modern problems require modern solutions.

Farmers in southern India rely on wild bees for pollination. Giant honey bee (*Apis dorsata*) on cardamom bloom, photographed by Margie Mayfield.

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Dirty Work, Done Dirt Cheap

Sacha Spector and Elizabeth Nichols

This article is based on a review by the authors and a team of collaborators in ScarabNet (www.scarabnet.org), which appeared in volume 141 of the journal Biological Conservation.

Imagine, if you will, a pasture, carpeted in cow dung, baking in the hot midday sun. Add to your mental picture swarms of biting flies, unpalatable weeds growing in the gaps between the hardening cow pats, and just for good measure, a stream overgrown with algae nourished by runoff from all that dung. Now scale up this vision so that it stretches to the horizon in all directions.

This may sound like one of Dante's circles of hell, but it was the reality facing Australia's livestock industry in the 1960s after it unwittingly undertook an experiment to see what the world would be like without dung beetles. Cattle, introduced to a land where the native dung beetle species were adapted to feed on the dry pellets produced by kangaroos and other marsupials but not the waste of ungulates, deposited thirty-three million tons of dung each year into an ecosystem that had no ecological mechanism for dealing with it. Pastures were smothered while populations of pest flies, both native and introduced, exploded. General misery, human and bovine, abounded. Dante himself would probably have shuddered at the sight.

To the rescue came a host of dung beetle species, introduced from southern Africa by an emergency dung beetle program of Australia's Commonwealth Scientific and Industrial Research Organization. Eight species ultimately established themselves on their new continent and, like Hercules cleaning the Augean stables, they mucked out Australia's pasturelands. The introduced beetles eventually reduced the area of Australia covered by pats of dung by 4 percent, which was a tremendous gain given that cows avoid eating the grass surrounding an additional 6 to 12 percent of the area around each dung pat. Today, introduced dung beetles are such an integral part of raising cows in Australia that there are even consulting companies that will help introduce dung beetles to your property, either for improving pasture health or for reducing nutrient runoff into waterways.

While Australia's pastures are a well-known example of dung beetles' importance in preserving pasture health, a recent study by John Losey and Mace Vaughn estimated the net value of dung beetles to the extensively pastured beef cattle industry in the United States at $380 million per year in avoided costs in fertilizer application and production losses from forage fouling, enteric parasites, and flies. When one considers that extensive pasture systems account for 78 percent of all agricultural land use globally—currently covering nearly five billion acres (two billion hectares) or about 15 percent of the earth's ice-free land surface—it quickly becomes clear that not only is the contribution to pasture health from dung beetles worth billions of dollars each year, but the integrity of our food production system relies in no small part on these tiny animals.

In fact, the roughly six thousand species of dung beetles in the subfamily Scarabaeinae play key roles in providing a wide range of important ecosystem functions and services around the world. And it all starts with that lowliest of habitats, a pile of crap. For the most part, dung beetles are coprophagous—species feed on the microorganism-rich liquid component of the dung of mammals (and less commonly that of other vertebrates and invertebrates, as well as rotting fruit, fungus, and carrion). They use the same materials to create brood balls that they provide for their offspring in subterranean nest-tunnels. As they consume and relocate dung to their nests, dung beetles carry out ecological processes that include nutrient cycling, soil aeration, secondary seed burial, and parasite suppression.

The most obvious result of all that eating and burying is that the landscape doesn't become overwhelmed with residual wastes. Trond Larsen, in his study of the islands created when a massive hydroelectric project formed Lago Guri in Venezuela, found that islands that had retained their populations of howler monkeys but lost their dung beetles soon had piles of monkey dung a meter tall under favorite resting trees!

The burial of all that nutrient-rich dung, though, also has significant impacts on the structure and fertility of the world's soils. From several studies of nutrient cycling in pastures and grasslands, we know that dung beetles can increase the levels of available nitrogen, potassium, phosphorus, calcium, and magnesium in soils. Nitrogen especially may be impacted: by burying dung under the soil surface, dung beetles prevent the loss of nitrogen through ammonia volatilization and increase the nitrogen available for uptake by plants through mineralization. Without dung

Onthophagus carbonarius **lives in central and southern Africa, making a living from the dung piles of elephants and other large mammals. Photograph by Piotr Naskrecki.**

beetles to transfer these nutrients into the soil layers, they would likely be lost either by being leached away or by volatilization. Also, as they tunnel into the ground, the larger beetles may significantly increase aeration of the soil, improving its capacity to build organic layers, exchange gasses with plants, and hold moisture.

As dung beetles enhance the world's soils, they in turn enhance the productivity of the primary producers, the plants. A raft of experimental studies have linked dung beetle bioturbation and nutrient-mobilization activities to increases in plant biomass, plant height, grain production, protein levels, and nitrogen content. Several other studies have shown that the benefits of dung beetle nutrient mobilization on plant growth rival the application of chemical fertilizers.

Dung beetles also help plants in another critical process, secondary seed dispersal. Particularly in the tropics, many plants require vertebrates to move their seeds away from the parent plant. Once the seeds are voided in the vertebrates' dung, though, they are highly vulnerable. Seed predators like rodents and lygaeid seed bugs can consume over 90 percent of seeds that are left exposed, and fungi and pathogens can quickly destroy the viability of those that remain. Dung beetles quickly move a large percentage of seeds horizontally, away from the intense predation and seed-to-seed competition near the dung pile or parent tree. They also move seeds vertically into the soil, where conditions for

Naturally found in southern Europe and Africa south of the Sahara, the bronze dung beetle (*Onitis alexis*) has been introduced into Australia and North America to clean up after cattle. Photograph by Piotr Naskrecki.

Dung beetles can rapidly sense and locate fresh dung. This *Euoniticellus kawanus* has just landed, and is still folding away its wings. Photograph by Piotr Naskrecki.

germination may be better than on the surface. This latter benefit depends on the size of the beetle doing the burying, however, since large dung beetles routinely dig tunnels a meter deep, which is well below the germination zone of most seeds. (In this case, dung beetles become seed predators too.)

As the Australians learned, dung is the breeding habitat for many species of pestiferous flies. It is also involved in the transmission routes for disease-causing nematodes and protozoans that can infect livestock, wildlife, or humans. Dung beetles, as they feed and manipulate dung during burial, significantly reduce or control the abundance of those flies and parasites, with potentially tremendous implications for health.

One study found that cattle dung pats without dung beetles had fifty times as many helminth (internal parasitic worm) larvae as those with healthy dung beetle populations. Another experiment showed that boosting the density of dung beetles in pastures by a factor of five led to a nearly 75 percent reduction in the number of parasitic nematodes compared to pastures with normal dung beetle density—and a reduction of more than 93 percent compared with pastures with no dung beetles at all. In real terms this translates to hugely reduced parasite loads in livestock animals, with corresponding gains in meat production. For wildlife, the impacts of dung beetles on health are unknown but thought to be huge. For us humans, it means lower incidences of parasites like *Giardia*, *Cryptosporidium*, and *Ascaria* in our landscapes and potentially fewer health-damaging infections.

Dung beetles have been working to exploit vertebrate dung as a resource for at least the last forty million years. In fact, recent fossil evidence of dung-packed burrows strongly suggests that dung beetles evolved toward coprophagy in the prodigious dung piles of dinosaurs well before the diversification of mammals. Today dung beetles, like many invertebrate groups, are declining under the pressures of habitat loss, over-application of wide-spectrum pesticides, and declines of the mammal species on which they depend. In a recent review of the literature we found that, around the world's tropical regions, there is a clear signal that forest-dwelling dung beetles are disappearing from increasingly agricultural landscapes.

Dung beetle functions may be maintained in pastures and croplands by a handful of wide-ranging "super-tramp" species able to disperse efficiently and quickly colonize and thrive in those hot, open agricultural areas. But what will be the fate of the tropical forests when their diverse assemblages and specialized species of dung beetles wither away due to overhunting of the mammals they depend on? What will happen to our pastures as we continue to apply endectocides (chemicals used to kill internal and external parasites), such as deltamethrin, that remain lethal to dung beetles even after the chemicals pass through cows' guts and into their dung, leading to an all-too-common sight of a ring of dead beetles around each cow pat in a pasture?

We don't yet have answers to these questions. But it is increasingly clear that we ignore our dung beetles not just at the risk of letting such a long, fascinating lineage of insects slip through our fingers, but at the risk of jeopardizing the billions of dollars worth of vital, but free, services they provide.

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Elizabeth Nichols is a Ph.D. student at Columbia University whose research focuses on the functional consequences of insect diversity loss.

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In most of the world, poor farmers grow crops for subsistence. Few governments devote financial resources to helping poor farmers develop modern adaptive practices to allow them to improve their quality of life while farming sustainably. Pollination is certainly not the only issue faced by the world's poor farmers, but many practices that are good for pollinators are also good for the health of farmland in general.

It is to be hoped that in coming years the growing international attention to bees as crop pollinators may spur other nations to follow India's lead in helping subsistence and commercial farmers farm sustainably in the modern world.

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XERCES NEWS

Expanding Efforts to Protect Pollinators Nationwide

This is an exciting time for the Xerces Society's pollinator program! We have worked successfully with a coalition of conservation and agriculture groups to include language in the 2008 Farm Bill to provide financial incentives to restore pollinator habitat in the United States and research funding to address conservation of honey bees and native bees.

Implementation of the Farm Bill has put us in an excellent position to collaborate with agricultural professionals to put pollinator conservation into practice. As part of this effort, the Xerces Society and the USDA's National Resource Conservation Service (NRCS) have created a joint, national-level pollinator conservation position. And, with Xerces staff now based in three states (Oregon, Wisconsin, and, California), we can reach many more people.

Xerces staff members are working with NRCS state offices across the country. We have conducted dozens of workshops for NRCS staff, and have developed a variety of information materials for NRCS and other agriculture-related staff including state and national pollinator conservation technical notes, guidelines on using Farm Bill programs to create pollinator habitat, and methods for assessing the value of existing habitat. Visit our new website for more information and access to fact sheets and conservation guidelines.

The combination of the Farm Bill and the NRCS collaboration offers an amazing opportunity for pollinator conservation. Over the next year we will keep working broadly across the United States to improve habitat for important pollinator insects.

Update on the Butterfly Big Year and Butterfly-A-Thon

After an initial few months of mostly gray and rainy weather, and the occasional mechanical glitch with his trusty car Powdermilk, Robert Michael Pyle has seen his luck improve as he continues his epic year-long quest to have in-depth encounters with a record number of North American butterflies. To date, he has positively identified more than 460 distinct species and is closing in on his personal goal of five hundred species by year's end.

Having already traveled thousands of miles and visited nearly every state, Bob will continue searching until the final days of 2008. With the help of Xerces members and supporters, Bob's efforts have raised tens of thousands of dollars in support of the Society's efforts to protect rare and endangered butterflies through our Butterfly-A-Thon. For those who have made pledges, we will be sending out pledge fulfillment requests at the beginning of next year.

For more on Bob's continuing adventures, or to make a pledge, please visit our Butterfly-A-Thon webpage at www.xerces.org / butterflyathon.

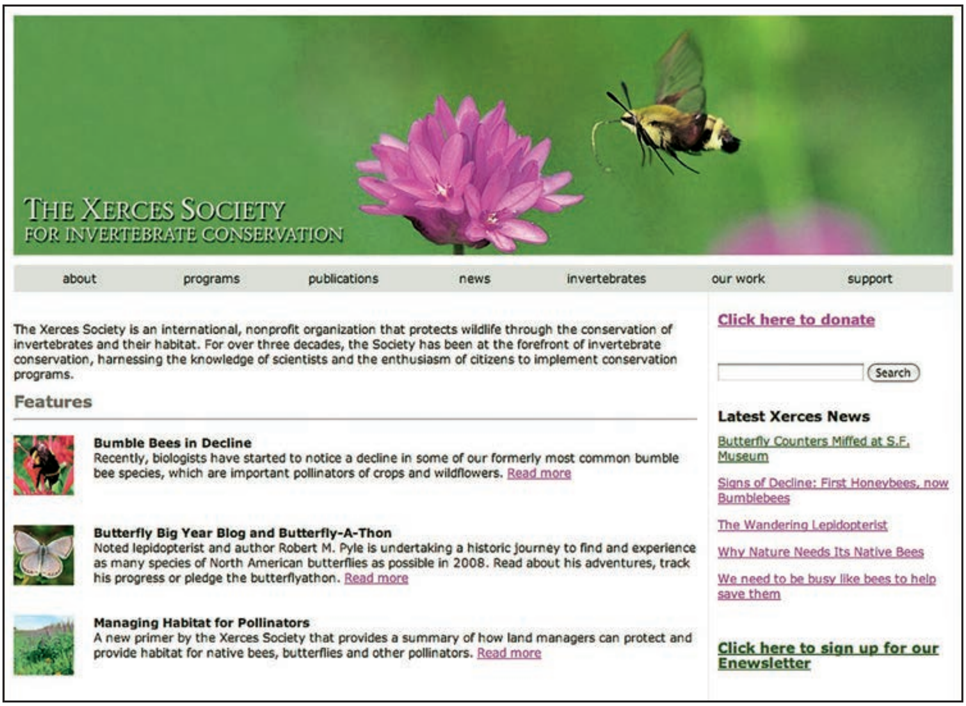
Xerces Society Website Metamorphosis

We are pleased to announce the launch of our newly redesigned website—at www.xerces.org—with greatly improved design and accessibility, and many additional resources. With hundreds of pages of information, the Xerces Society's new website is a vital source of information for those interested in invertebrate conservation. In addition to summaries of the Society's conservation programs, the website offers access to dozens of free, easy-to-download fact sheets and conservation guidelines.

We're grateful to the many extraordinary photographers whose images grace our new site, and to Green Tangerine Media, whose technical skills made it possible. Some highlights of the site:

◆ We've posted helpful information from our Pollinator Conservation Program, for farmers, landowners, gardeners, wildland and park managers, and golf course superintendents, on providing habitat for pollinator insects.

◆ You'll find Robert Michael Pyle's Butterfly Big Year blog detailing his year-long odyssey crisscrossing the United States in pursuit of as many different species of butterflies as possible, along with information on the Xerces Society's Butterfly-A-Thon.



The Xerces Society's newly redesigned website is attractive and easy to navigate. On the site you'll find hundreds of pages of conservation information, as well as dozens of publications and fact sheets available for download. Visit us at www.xerces.org.

◆ We've developed and posted profiles of more than a hundred rare and at-risk invertebrate species, each with information on life history, status, and conservation needs.

The profiled species include a broad array of invertebrates, ranging from Susan's purse-making caddisfly (a critically imperiled species found in just a single creek in Colorado) to the rusty-patched bumble bee, once very common throughout the eastern and upper midwestern regions of the United States, but in steep decline in recent years.

◆ You can sign up for the Xerces Society eNewsletter, which will provide you with periodic email updates on invertebrate-conservation issues.

◆ In addition, our website provides information about our publications, and now offers, via PayPal, the opportunity to purchase Xerces Society publications and memberships online.

New Staff Members at the Xerces Society

We are delighted to introduce three new members of our staff who are helping to expand our conservation work and our geographic spread. Eric Mader, our pollinator outreach coordinator, works out of our new office in Madison, Wisconsin, providing technical assistance, support, and workshops to agricultural professionals throughout the eastern United States. Jessa Guisse, our pollinator outreach coordinator for California, is expanding activities there, traveling the state to help farmers and agricultural professionals find better ways to protect farms and harvests. Sarah Foltz, a conservation associate based in our Portland office, will work to better understand the needs of endangered invertebrates and assist in our efforts to evaluate the health of wetlands.

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In this mouth-like image of a mussel, the flapping "lips" are a lure to attract fish and the "teeth" are pouches containing glochidia, the larval mussels. When a fish attacks the lure, glochidia are released and hitch a ride on the fish. Black sandshell (*Ligumia recta*), photographed by M. C. Barnhart.

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Our cover photograph shows the nymph of a band-winged grasshopper (genus *Xanthippus*). These grasshoppers feed on grasses, and are found at a range of altitudes from mountains to plains and in a diversity of habitats. Photograph by Bryan E. Reynolds.