WINGS

ESSAYS ON INVERTEBRATE CONSERVATION

THE XERCES SOCIETY FALL 2014

CONTENTS

This issue of *Wings* is mostly about butterflies and moths: their importance as pollinators; how atalas disappeared from south Florida and then returned; and the challenges in captive rearing of endangered invertebrates such as the quino checkerspot.

Protecting Pollinators: A Critical Issue of Our Time

Scott Hoffman Black

This spring I participated in a meeting at the White House to discuss how the federal government can better respond to the threats facing the nation's pollinators. Both at the meeting and through a letter to President Obama, I promoted the Xerces Society's holistic approach to protecting native pollinators such as our agriculturally important bumble bees and the much-loved monarch butterfly. This approach includes protecting and restoring habitat, and using strategies that minimize the use of insecticides across farms, urban and suburban areas, and our wild spaces.

In June, President Obama released a memorandum to the heads of federal agencies titled "Creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators." Many of the recommendations presented at the meeting and in our letter to the President were included in the memorandum, which specifically mentioned native bees and monarch butterflies. The President declared that "it is critical to expand Federal efforts and take new steps to reverse pollinator losses and help restore populations to healthy levels."

Federal agencies are charged with creating conservation strategies to address these issues. We are helping these agencies by providing guidance, technical support, and pollinator expertise so

The American bumble bee (*Bombus pensylvanicus*) is one of many bee species in North America that may benefit from federal action resulting from President Obama's memo. Photograph by Bryan E. Reynolds.

that they can effectively protect pollinators and their habitat. Here are just a few examples of our recent collaborations:

When the "Three Amigos"—President Obama, President Nieto, and Prime Minister Harper—met at the North American Leaders' Summit in February, they promised more action to protect the monarch butterfly. As a result, the North American Monarch Conservation Plan is being revised. A few weeks ago, under the leadership of the U.S. Fish and Wildlife Service, an interagency "High Level Federal Monarch Working Group" was formed to address the revisions within the United States. Agency heads from the U.S. Forest Service, the National Park Service, the Bureau of Land Management, the Federal Highway Administration, and the U.S. Department of Agriculture's Natural Resources Conservation Service are involved. I was appointed as one of two ex officio members, along with Karen Oberhauser from the University of Minnesota, in our role as co-chairs of the Monarch Joint Venture. Mexican agencies are also working on their portion of the plan. In September I traveled to Valle de Bravo, Mexico, to meet with agencies in that country, and to provide context about U.S. efforts as well as recommendations for revising the plan.

To conserve monarchs and their habitat, we are working with U.S. national wildlife refuges and the other members of the Monarch Joint Venture to provide advice and milkweed seed for monarch restoration efforts; with the U.S. Geological Survey to develop habitat restoration and conservation strategies for monarchs; and with the U.S.

Habitat is the key to sustaining existing populations of bees and butterflies, and is the focus of much of the Xerces Society's pollinator conservation work. This new habitat strip was planted in fall 2013 by Xerces staff. Photograph by Brianna Borders.

Forest Service to provide feedback on a conservation strategy for monarchs on Forest Service lands. We are also working with NatureServe—whose network of natural heritage programs informs conservation policy across the United States—to update the status assessment for both eastern and western monarch populations.

Working with ICF International through a contract with the Federal Highway Administration, Xerces is developing best management practices for pollinator conservation on roadsides. These practices will guide restoration and management by state departments of transportation nationwide.

We are working with the Natural Resources Conservation Service to provide additional incentives for pollinator restoration on farms. With guidance from our pollinator staff, new initiatives have enabled growers to restore tens of thousands of acres of farmland for pollinators.

The first product of the President's memorandum has just been released, a report from the White House Council on Environmental Quality that provides guidance on ways that federal agencies can incorporate pollinator-friendly practices in new construction, building renovations, landscaping improvements, and facility leasing agreements at federal facilities and on federal lands. To put this in context, the federal government controls or owns more than forty-one million acres of land and well over four hundred thousand buildings in the United States. That's a lot of property that can be made better for pollinators—and these actions can act as examples and catalysts for other governments or organizations. The Xerces Society's work is well reflected in the report, and our books, reports, and online materials are all included as key resources.

Populations of monarchs (*Danaus plexippus*) have declined significantly in recent years. Photograph by Bryan E. Reynolds.

Although we work closely with many government agencies, we are also willing to speak up when they are not doing enough for pollinators. For instance, we believe that the Environmental Protection Agency should better regulate toxic insecticides, and we are pushing for action through the Saving America's Pollinators Act. We are also working to get protection for our country's most imperiled pollinators under the Endangered Species Act.

By partnering with these agencies and simultaneously pushing them to do more, we believe that we can achieve better protections for these vitally important animals and a more secure future for the generations ahead who will rely upon their services.

Butterflies and Moths as Pollinators

Candace Fallon, Scott Hoffman Black, and Matthew Shepherd

In 1862, Charles Darwin received a package of orchids from Robert Bateman, a British orchid grower. Darwin had been studying the pollination of orchids for many years, so it was no great surprise that people would send him specimens. What was surprising, however, was that one of the orchids sported nectaries, tubular spurs from the flowers containing nectar at the bottom, nearly a foot long. In disbelief, Darwin wrote to his good friend, botanist Joseph Hooker, "Good Heavens! What insect can suck it?"

The orchid was *Angraecum sesquipedale*, a beautiful species from Madagascar with large, white, six-pointed flowers. After examining the orchid and experimenting with pushing tubes down into its nectaries, Darwin reached the conclusion that the only insect capable of reaching the nectar would be a moth with an extraordinarily long tongue—in fact, far longer than that of any moth known at the time. Later that year, Darwin published *The Various Contrivances by which Orchids are Fertilised by Insects*, in which he made his now-famous prediction that there "must be moths with proboscides capable of extension to a length of between ten and eleven inches!" He was correct, although it took more than forty years until anyone found such a moth on Madagascar, a subspecies of the African hawk moth *Xanthopan morgani*. It was given the subspecies name *praedicta*, in recognition of Darwin's statement.

Nectar in itself does not help the plant grow, so why on earth does a plant produce it? And why do some plants go to such lengths to conceal it so deeply? A growing body of evidence suggests that moths—and, counter to what many researchers have long believed, butterflies as well—are significant pollinators of at least some species. And for these animals, nectar is the main attraction.

For plants, an essential step in reproducing is pollination, the sharing of pollen among their own flowers or with those of other plants of the same species; the flowers both disseminate their own pollen and receive it from other flowers. Plants, though, are—literally—rooted to the spot and cannot move about in order to accomplish this transfer. Approximately 20 percent of flowering plants release and receive their pollen on the wind, with grasses being one of the major groups of such wind-pollinated plants. The great majority of flowering plants, the other roughly 80 percent, rely on animals, mostly insects, to move their pollen about.

For some animals, bees in particular, the pollen is a source of food, reason enough in itself to visit a flower. But for many other insects, as well as for birds and other animals, the nourishment that draws them is nectar. Brightly colored flowers or heady fragrances advertise the presence of nectar, and special color patterns and markings help to direct the pollinators quickly to their reward. Then, while feeding, the animals

inadvertently pick up pollen grains, which, as they continue feeding, they transfer to other flowers of the same plant species. When nectar is hidden deep within the flower, it can ensure that only a particular pollinator visits a given plant species, and that the visitor contacts the pollen in just the right way.

Numerous birds pollinate: hummingbirds in the Americas, sunbirds in Africa, honeyeaters in Australia and the Pacific Islands. Some mammals are also known to be pollinators. There are several species of bats that pollinate trees in the tropics, and others that pollinate saguaro cacti in the deserts of Mexico and the United States. Non-flying mammals that pollinate include sugar-gliders in Australia and lemurs on Madagascar; those lemurs, at more than five pounds (two and a half kilograms) may be the heaviest pollinators in the world.

The most significant pollinators, however, are tiny: bees (Hymenoptera),

The exceptionally long spurs on the orchid *Angraecum sesquipedale* led to Charles Darwin's famous prediction of a moth with a ten-inch-long tongue. Etching by Henry George Moon, 1888.

Pollen is clearly visible attached to the legs of this obscure skipper (*Panoquina panoquinoides*) drinking nectar from camphor daisy. Photograph by Bryan E. Reynolds.

beetles (Coleoptera), flies (Diptera), and butterflies and moths (Lepidoptera). Bees are by far the dominant pollinators of crops, and it is generally agreed that, in temperate areas of the world, bees are the most important pollinators for plants of all kinds. Flies, though, become increasingly important for pollination in high-elevation and high-latitude regions, while beetles grow in importance in tropical and equatorial areas, and are major pollinators of rainforest trees.

Which brings us to the Lepidoptera. Although not as centrally critical for pollination as bees are, butterflies do play a significant role in the pollination of flowering plants. There is plenty of established evidence that moths can be important pollinators, but some have questioned whether butterflies serve this function at all. Butterflies certainly pick up pollen when visiting flowers; there are photographs of skippers, for instance, in which pollen can be clearly seen on their legs and bodies. We have observed and documented grass skippers (subfamily Hesperiinae) carrying pollen, and skippers may in fact be important pollinators of prairie areas, since their short legs and stout hairy bodies lend themselves to moving pollen from flower to flower. Similarly, monarch butterflies may be seen with pollinia—small bundles of pollen—hanging from their legs, picked up from the milkweed flowers they visit.

For any animals to be successful pollinators, they must carry pollen from the flower of a particular kind of plant to another flower of the same kind. Bees are efficient pollinators in part because they demonstrate considerable flower constancy, moving consistently among flowers of the same species and even returning again and again to a single spe-

cies in separate foraging flights to gather more pollen. Although butterflies show less constancy to flower species, they are consistently drawn to flowers from which they can efficiently get nectar. Butterflies and moths may not be as effective as bees in moving pollen and thereby pollinating plants, but, even so, it has been documented that many plants benefit from the transfer of pollen by these insects.

In North America, the western prairie fringed orchid (*Platanthera praeclara*) is pollinated by several species of hawkmoths in Midwest prairies; the mountain parnassian (*Parnassius smintheus*) pollinates *Senecio* and other yellow flowers in the daisy family in montane areas of the western states and northward through Canada into Alaska; and in the meadows and forests of the Pacific Northwest, swallowtails (*Papilio* spp.) are pollinators of the Columbia tiger lily (*Lilium columbianum*). In Central America, the firecracker plant (*Russelia* sp.), a shrub with vibrantly colored flowers, is pollinated by the orange barred sulfur butterfly (*Phoebis philea*); the shrub's weeping branches cause its flowers to hang in such a way as to make it difficult for other insects to pollinate. In Jamaica, tropical buckeyes (*Junonia evarete*) pollinate their host plants, including porterweed and snakeweed (genus *Stachytarpheta*).

Europe also has a number of plants that are pollinated by Lepidoptera, in particular orchids that are adapted to butterflies and moths. The fragrant orchid (*Gymnadenia conopsea*) and the

Six-spot burnet moth (*Zygaena filipendulae*) resting on fragrant orchid, one of several European orchids that has adapted for pollination by moths. Photograph by ArtMechanic, Wikimedia Commons.

closely related short-spurred fragrant orchid (*G. odoratissima*) are both pollinated by owlet and forester moths. The greater and lesser butterfly orchids (*Platanthera chlorantha* and *P. bifolia*) may be misnamed, as owlet and hawk moths are their most frequent visitors. Each of these orchids produces copious amounts of nectar, unlike the pyramidal orchid (*Anacamptis pyramidalis*)—which doesn't produce any, and which yet somehow attracts both butterflies and moths and succeeds in achieving adequate pollination.

Another example of butterfly-pollinated flowers comes from the fynbos shrublands of South Africa's Cape Province. What makes this instance most notable is that one butterfly, the Table Mountain beauty (*Aeropetes tulbaghia*), is the pollinator of a group of about fifteen unrelated but visually similar flowers; such dependence on a single species of pollinator is rarely found in plants, let alone in a group of different species. These flowers all bloom in late summer and have large, red flowers with straight, narrow nectar tubes; the butterfly appears to be attracted primarily to the red color of the flowers, while the narrow nectar tubes discourage birds that would otherwise visit red flowers. At least one of these species, the rust red orchid (*Disa ferruginea*), does not offer

The Table Mountain beauty butterfly (*Aeropetes tulbaghia*) is the central figure in a web of remarkable plant–insect relationships. More than a dozen similar-looking but unrelated species of flowers rely on the butterfly for pollination. Photograph by Steve Woodhall.

nectar but, instead, in order to attract the butterfly, mimics species that do.

Many butterfly-pollinated plants share a set of similar features. They tend to bloom during the day and to provide nectar at the bottom of a long, narrow tube or spur. The flowers, growing singly or clustered together in a group, often have a sweet odor, and typically provide a large enough surface for a butterfly to land upon. The flowers are also in colors that butterflies can see, usually red through violet on the color spectrum, and often in ultraviolet. To make it even easier for butterflies to find the nectar (and thus further aid the plant's reproductive success), some plant species have evolved nectar guides—colorful lines or markings on the flower—which help direct the pollinator to the nectar. In some cases, these nectar guides contain ultraviolet patterns that only particular flower visitors can see. Flower species with nectar guides are more frequently visited by pollinators than are those without guides.

Nectar is an energy-rich blend of sugars (typically fructose, glucose, and sucrose) combined with amino acids, sometimes with lipids, antioxidants, and alkaloids mixed in. It is the primary food source for most adult butterflies and moths and is thus the major attractant to flowers—although, as the pyramidal and rust red orchids demonstrate, nectar is not entirely necessary if the insects can be fooled into visiting anyway.

Darwin's investigation of orchids showed that some plants have adapted their shape to ensure pollination. Few of those adaptations are as extreme as foot-long nectaries, but many flowers secrete nectar in spurs whose depth correlates to the length of the tongue of a particular species. As butterflies and moths travel from flower to flower to feed, the pollen collecting on them gets brushed off, increasing the plant's chances of a successful future. That butterfly you watch moving about in your garden or dancing over a meadow brings more than just beauty. It represents millennia of evolution and carries life with it as it flies in the sunshine.

The pyramidal orchid tricks butterflies and moths; they visit to drink nectar but find none. Photograph by Olivier Prichard, Wikimedia Commons.

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The Ecological and Social History Of the Atala Butterfly in Southeast Florida

Gil L. Pettigrew

Southeast Florida's atala butterfly (*Eumaeus atala*) is an example of a conservation success story. The atala disappeared from many places, reaching its nadir in the middle of the twentieth century when the butterfly was believed to have vanished from Florida. Its rediscovery in 1959 sparked an attempt to reintroduce the atala to the Everglades National Park and, eventually, led to its return to gardens and natural areas region-wide thanks to a combination of state-government protection and the actions of a community of enthusiasts.

The fate of the atala is closely tied to that of its host plant. From the late nineteenth century through the early twentieth, the atala experienced a precipitous decline due to the commercial harvesting of its larval host plant, coontie (*Zamia pumila*). The effect was compounded by intensive development of the butterfly's pine rockland and coastal hammock habitats, and atalas were not in evidence in Florida from 1937 to 1959.

Since that time, their numbers have increased, due in large part to the popularity of coontie as a garden and landscape plant and to the deliberate introduction of atalas on private and public lands. Even so, the atala is still considered a vulnerable species, with many of

The bright colors of the atala butterfly (*Eumaeus atala*) warn of its unpalatability. Photograph by Scott Zona, Wikimedia Commons.

Coontie has a checkered history in Florida. It is now a popular garden plant and commercially grown for the landscape industry. Photograph by Gil L. Pettigrew.

its populations ephemeral or scattered.

The atala is a hairstreak, in the subfamily Theclini of the gossamer wing butterflies. It is large for a hairstreak, with a wingspan of up to two inches (five centimeters), and unlike any other: its velvet-black wings shimmer with blue iridescence; its hind wings sport three curved rows of glittering blue spots and a bold orange patch; and its abdomen is bright orange. Even in its immature stages, it is distinctive: its larvae are red-orange with a double row of yellow spots along each side, and its pupae are solid orange-red.

Like its cousin, the Mexican cycadian (*E. toxea*), the atala is aposematic: bright warning colors at all life stages signal that it is distasteful to most vertebrate predators due to its ability to absorb from coontie a neurotoxic molecule called cycasin. Invertebrates, however, are not deterred; ants are significant predators of atala eggs in many localities, and larvae may be taken by assassin bugs. As with many other chemically protected insects, atalas frequently aggregate. Adults, pupae, and larvae are routinely found in groups, reducing the chance for any given individual to be taken by an inexperienced predator.

Atalas are active all year in south Florida, but they are most conspicuous during March and April and again in October through December, when they deposit whitish-yellow eggs in small clusters on the fresh coontie fronds that sprout after spring and fall rains.

The caterpillars feed on the coontie fronds, occasionally defoliating entire plants and causing enough damage for gardeners and horticulturalists to re-

Even atala caterpillars have bright colors to warn predators off. Photograph by Patrick Coin, Wikimedia Commons.

gard them as pests. Atala larvae pupate after the fourth or fifth instar, typically on or near where they've been feeding, with adults emerging within two weeks. The adults are not very active, spending much of their time resting in shaded areas, frequently on large leaves. Nor do they fly quickly—their toxicity means they don't have to.

Because not every habitat within their range meets their needs, atalas occur in small, disjunct, often ephemeral subpopulations within larger metapopulations. These are found in urban yards, suburban gardens, and a range of natural habitats in Monroe, Miami-Dade, Broward, and Palm Beach counties. Atalas have been reported from a few other counties in south Florida—and there are even isolated records from north Alabama and southern Illinois, although these tropical butterflies cannot survive for long in such places.

The butterfly's small, isolated populations are vulnerable to cold spells, pesticide use, hurricanes, floods, local habitat destruction, and depletion of food plants by overexploitation. Inbreeding depression may also be a factor, especially in introduced populations that originate from a small number of individuals or are too isolated to ensure adequate gene flow. The transient nature of atala populations is often a challenge for conservation, because many introduced populations do not persist. On the other hand, the butterflies sometimes return when conditions improve, and they also establish populations on their own in suitable areas near existing colonies.

Coontie is the atala's only native Floridian host plant, and the only cycad native to the United States. It belongs to a genus comprising fifty species found in Mexico, the Caribbean, and Central and South America. Although it is a tropical or subtropical plant, it can endure temperatures of 15 degrees Fahrenheit (–9.5 degrees Celsius) for short periods and will thrive well outside the butterfly's range.

A beautiful plant, coontie is vaguely palm-like, with a squat, rough-barked trunk and bushy fronds of thick, shiny, pinnate leaves. It is is durable and able to grow in full sun or partial shade in a variety of natural and disturbed environments, although it prefers sandy, well-drained soil. Coontie is also somewhat salt-tolerant and can grow near brackish water. This toughness is key to its success in such domestic spaces as gardens and yards, and even in highway medians and at bus stops.

Coontie has long been harvested by indigenous Americans who would grind its roots into a starch-rich flour. In the mid-nineteenth century commercial coontie mills began to be established around south Florida for the production of arrowroot starch, which was used in breads and wafers, as a thickener for soups and gravies, and as laundry starch. It takes about five hundred pounds of coontie root to produce a hundred pounds of starch. By the 1920s the slow-growing plant had been decimated in Florida, and it existed only in fragmented populations. The atala butterfly vanished with it, considered extirpated until 1959, when a small population was discovered in Broward County.

Currently, the atala is not federally listed as endangered or threatened, although it does have a number of state or regional classifications. It is listed as rare and vulnerable by the Florida state government, and it is also listed under the state's Comprehensive Wildlife Conservation Strategy as one of Florida's species in greatest need of conservation. The atala is listed as "vulnerable" by the International Union for Conservation of Nature Red List; and the South Florida Multi-Species Recovery Plan prepared by the U.S. Fish and Wildlife Service identifies the atala as a "species of management concern."

The lack of federal protection, ironically, benefits atalas in one way: these butterflies can be collected from and transported to private property without a permit. The result is an atala "underground" of butterfly fanciers. Gardeners plant coontie and exchange atala chrysalises or caterpillars, establishing informal micropopulations on private properties. There have been officially organized introductions at the Everglades National Park, and at state, county, and city parks. Botanical gardens, school gardens, and university campuses have also joined in this effort. Community organizations, such as local chapters of

Female atala (*Eumaeus atala*) laying eggs on coontie, the butterfly's host plant. Photograph by Kenneth Setzer.

the North American Butterfly Association and south Florida's Urban Paradise Guild, have played a role in atala conservation via introduction and monitoring projects.

This success has not been universally applauded. For some people there can be too much of a good thing, atala-wise. Commercial horticulturalists growing cycads—including non-native species that atalas will eat—consider the butterfly a pest, sometimes resorting to lethal control to protect their plants. Some, on the other hand—the Montgomery Botanical Center in Coral Gables, for example—gather problem caterpillars and make them available to gardeners wanting their own atala colony.

Despite the efforts and enthusiasm of gardeners and land managers, the success rate of atala reintroductions is not precisely known due to a lack of baseline data on population size, population growth rates, developmental rates at different times of the year, and so on. Obtaining such fundamental information, and sharing it with professional naturalists and scientists, makes an excellent citizen science project for local environmental groups, schools, scouts, and families. In the role of a volunteer steward of butterfly habitat creation and rare butterfly reintroduction with the Miami-based Urban Paradise Guild, I am working with local volunteers at Oleta River State Park, Arch Creek Park, and other Urban Paradise Guild project sites to carry out monthly monitoring. By recording the number of atalas at various life stages every month, it is possible to generate simple graphs that show the developmental dynamics of the species throughout the year.

The enthusiasm for this striking butterfly—spurred on by an element of local pride born of its uniqueness to south Florida—has led to many efforts to protect it, which have increased the number of atala populations and individuals. The atala also serves as an umbrella species: creating and preserving habitat for the butterfly can provide living space for other, perhaps less charismatic, invertebrates. The breadth of community involvement in sustaining the atala is remarkable, giving those interested a sense of agency and ownership, and with luck it can serve as a model for the conservation and recovery of rare butterflies elsewhere.

The author is grateful to the following for collectively sharing their knowledge, and for their dedication to protecting this butterfly: Sandy Koi, doctoral student at the University of Florida; Frank Schena, south Florida eco-historian, naturalist, and president of Royal Palm Tours of Miami; Dr. Susan Koptur, professor of biology at Florida International University; Sam Van Leer, executive director of the Urban Paradise Guild; Claudia Figueredo and other Urban Paradise Guild volunteers; and the Miami Blue (Miami) and Atala (Palm Beach) chapters of the North American Butterfly Association. A version of this article appeared in the summer 2013 issue of American Butterflies.*)*

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Pupal Cells and Pumpkin Seeds: A Continuing Education in Invertebrate Zoology

Paige Howorth

A huge bag of oatmeal. Millet spray. Pumpkin seeds. Bulgur wheat. Five jars of raw honey. Two local oysters. Three scallops. One coconut. As this random assortment of items rolled along the conveyer belt to the cashier at Whole Foods, I passed him my zoo credit card and waited for the inevitable. "The zoo, huh?" he said. "What are you feeding?"

That day, it was katydids and coconut crabs, but the discovery that I direct an invertebrate rearing program always prompts some interesting follow-up questions. One of the most common ones is this: "Did you go to school for that, or did you get stuck with it?" The idea that working with invertebrates at the San Diego Zoo could be seen as a punishment amuses me, especially when you consider the vast mystery that is the invertebrate world. I would argue that there are more challenges—and rewards—in cracking the code for invertebrate animal welfare and reproduction than for any other taxa.

But giving exhibit space to arthropods is a relatively new concept, even for the San Diego Zoo. After maintaining a temporary exhibit for four years, we opened our first dedicated invertebrate facility in 2007 and established the Entomology Department at the zoo in 2009. We currently participate in two captive rearing programs for endan-

Children have a natural wonder about insects, even when face to face. A love of these animals can lead to a desire to protect and conserve them. Photograph copyright San Diego Zoo.

gered insects, as well as conservation projects for monarch butterflies and other pollinators.

As a result, invertebrates now have a firm place in our animal-care division and an entire staff devoted to their welfare and sustainability. We manage between thirty and forty species at any given time and rear those species that we are capable of propagating long-term (crustaceans with a pelagic, or open ocean, larval stage, for example, are excluded from these efforts). We also trade specimens with our colleagues at other insectariums and receive occasional imports from overseas. All of these animals are displayed for more than three million visitors a year and are used for hands-on outreach and education.

Some of the species we maintain have fairly straightforward rearing requirements, while others are the bane of our collective existence. Challenges can be broad, such as lack of information on natural diet, behavior in the wild, or requirements for egg incubation. As a result, one must be systematic, curious, and contemplative to survive the highs and lows of "tinkering" in order to meet the needs of such a diverse group. Or, to paraphrase a colleague at a recent Xerces Society workshop on checkerspot butterflies: "You have to think like a larva."

With more than nine hundred thousand named species of insects alone (and maybe five million species of insects in total), however, larva-think isn't sufficient. Taxonomically speaking, we rear a variety of stick and leaf insects, cockroaches, beetles, mantids, grasshoppers, and true bugs, as well as a selection of aquatic insects. Across related classes, we raise whip spiders from Kenya, scorpions from Ghana, tarantulas from Latin America, and millipedes from all over.

These are our fundamental groups, and we use our work with them to guide the husbandry of related species. Yet because there are so many poorly known or completely unstudied invertebrates, we often find more questions than answers when bringing new species into the collection. Indeed, for novel species, it's very common for our research into husbandry and natural history to return a paucity of information. As a result, projects undergo substantial trial and error before a proper diet is discovered, for example, or the proper substrate for oviposition (egg laying) is revealed.

A recent case in point: prior to importing dragon-headed katydids (*Lesina intermedia*) from Malaysia, we were unable to learn very much about their food preferences or oviposition requirements. From necessity, therefore, we tried to unravel their natural history through their morphology and behavior—and the tinkering began.

Dragon-heads have thick, lacerating mandibles, much like predatory katydids. Although this weaponry is suggestive of predation, the dragon-heads recoiled from live insects. We tried seeds, because those mouthparts seemed to beg to chew or crush something (besides fingers). While most seed predators would have found something to love in the peanut butter sticks with oatmeal, rice seed, bird seed mix, and honey that we prepared, only the rice seed garnered even mild interest. We supplemented these with vitamin mix and even provided a "salt lick" in the form of sodium-infused gelatin cubes.

Eventually, we were stringing lavish orthopteran-kabobs with every food

Rearing little-studied species such as the dragon-headed katydid (*Lesina intermedia*) often requires educated guessing. The size and shape of this female's ovipositor offers clues about how and where she lays her eggs. Photograph copyright San Diego Zoo.

item or analog thereof conceivably in their diet in the wild: various kinds of produce, chitin supplement, bee pollen, freshly killed insects, fish flake, honey, nuts, seeds, grains. Detecting preferred items is often difficult, but the "all-in" diet worked, and these scavengers thrived. Pumpkin and sunflower seeds, buckwheat and barley, watery produce, and even popcorn topped the palatability list. And we now know that they do relish insects—they just prefer them dead.

While healthy, the dragon-head population nonetheless remained static. We never observed evidence of oviposition, despite copious mating and sperm transfer, and postmortem dissections of female animals routinely revealed an abundance of eggs. Something important was still missing.

The ovipositor is a specialized tool for egg deposition, and its structure yields secrets. The dragon-headed katydid's ovipositor is long, sword-shaped, and thin as a fingernail—yet flexible and strong. We read this message in it: "I require crevices to deliver these eggs, because I can't penetrate hard wood or drill into soil." In the beginning, we offered soft wood, rife with deep nooks and crannies, as well as split, rotten, palm trunks.

When nothing changed, we planted young banana trees, thinking that the katydids might deposit eggs in between the stems and leaves. Within weeks, jagged holes appeared at the base of the plants and, just like that, we had both eggs *and* the answers to our questions about the oviposition behavior and uses for the intimidating mouthparts. Those robust mandibles are well-suited for chewing into plant stems to allow for insertion of the flexible ovipositor, and the result is a beautiful arrangement of eggs

deposited between the curved sheaths.

This type of micro-troubleshooting is readily applicable to the challenges of our invertebrate conservation projects. Examples are the Lord Howe Island stick insect (*Dryococelus australis*) and the quino checkerspot butterfly (*Euphydryas editha quino*); although both come from insect orders with well-established captive husbandry regimes, these two species defy the baseline methodologies.

The conservation story of the Lord Howe Island stick insect is as compelling as any in the past century. It was believed extinct for more than eighty years, rediscovered on a barren island off the coast of Australia in the early 2000s, and ultimately plucked from the precipice of likely extinction largely by the captive rearing efforts of the Melbourne Zoo. There are only about a thousand specimens of these gentle black giants in the world, and, with the exception of a group in captivity on Lord Howe Island itself, almost all of them reside in Australia. The small population on Ball's Pyramid—the site of their tenuous presence in the wild, an isolated rocky island a dozen miles from Lord Howe Island—awaits reassessment.

Our puzzle with the Lord Howe Island stick insect is diet. So much time has passed since it lived on Lord Howe Island that only records of historical host plant preferences exist; when found on Ball's Pyramid, the insects were feeding on one scrappy *Melaleuca* bush. In captivity, however, they have now been reared on a number of host plants that were not historically in their range. As a result, the main focus of our program to date has been on identifying the host plant, and creating an adequate plant nursery on zoo grounds to ensure the success of this animal. This required trips Down Under specifically to retrieve seed and cuttings from host plants unavailable in the United States, as well as to observe the plant-provision regime at the Melbourne Zoo.

These nymphs of the Lord Howe Island stick insect (*Dryococelus australis*) were successfully hatched at the San Diego Zoo. Photograph copyright San Diego Zoo.

The endangered quino checkerspot butterfly has a fleeting, yet no less important, relationship with its host plant. The dwarf plantain senesces during the summer from San Diego south into Mexico, and, at this time, the butterfly larvae hibernate, or enter diapause. Throughout this period, they cease feeding, molt into a distinct larval form, and wait for the winter rains to stimulate germination of dwarf plaintain seeds. Part of the quino managed-care protocol involves creating artificially moist conditions to facilitate "breaking" diapause at the proper time. The environmental triggers for quino diapause are poorly understood, however, and in the lab larvae grown under exactly the same conditions can follow opposite developmental paths. Some go back to "sleep," while others feed, grow, and become butterflies. Much more study of their diapause requirements is needed to optimize protocols for rearing and release in recovery efforts.

As invertebrate populations shrink, and captive rearing is further utilized as a tool in conservation planning, it's great to have people poking around in unlikely places for the means to perfect their regimens. We've carved out artificial pupal cells from floral foam for rhinoceros beetles and administered commercial blackberry gel solution via syringe to stick insects. Colleagues in Omaha, Nebraska, use string to fish out endangered Salt Creek tiger beetle larvae from their burrows to prevent cannibalism; the perfect larval fishing string was found by unraveling an old towel. As well, friends in Rhode Island and Missouri have endured nauseating studies on the proper weight and shape of decomposing prey for American burying beetles, ultimately settling on 4.6-to-5.6 ounce (130-to-160 gram) quail as a target carcass.

Creating the correct conditions is the key to successful breeding of the quino checkerspot butterfly (*Euphydryas editha quino*). Photograph by Andrew Borcher.

In closing, I'll circle back to the earlier questions. I deliberately chose this path, and I did enthusiastically study for it. But "tinkering" is yet another deep and interesting rabbit hole. The outcomes—sustainably rearing collection animals, or aiding a conservation project—are the ultimate rewards, but it is the process of identifying the questions that sustains curiosity. So, if you can go to school for that, class has long been in session—and I am a devoted pupil.

Paige Howorth leads the Entomology Department and the invertebrate conservation programs at the San Diego Zoo. She serves on the steering committee of the Association of Zoos and Aquariums' Terrestrial Invertebrate Taxon Advisory Group.

The Migratory Dragonfly Partnership

With their brilliant colors and exuberant flight, dragonflies and damselflies (Odonata, or odonates) are conspicuous, appealing, easily recognized residents of almost any freshwater habitat. They are also important to the ecology of both aquatic and terrestrial habitats. Odonates may seem like a well-studied group, but in fact there is still a lot we don't know about their distribution, ecology, and behavior—especially when it comes to their annual migrations. The Migratory Dragonfly Partnership (MDP) is working to fill these knowledge gaps by investigating the annual movements and local life histories of migratory dragonflies in North America.

Formed in 2011 with ongoing support from the U.S. Forest Service International Programs, the MDP is a collaboration of scientists, nongovernmental organizations, academic institutions, and federal agencies from the United States, Mexico, and Canada.

The MDP is using research, citizen science, and education and outreach to engage volunteers to monitor the five main migratory dragonfly species in North America: common green darner (*Anax junius*), wandering glider (*Pantala flavescens*), spot-winged glider (*P. hymenaea*), variegated meadowhawk (*Sympetrum corruptum*), and black saddlebags (*Tramea lacerata*). With the help of training and resources provided though the MDP web site as well as full-day short courses that have been offered in Ontario, Canada; Veracruz and Tabasco, Mexico; and throughout the United States, the MDP has already built an international network of more than seven hundred volunteers who make observations and report data through its two main citizen science projects: Pond Watch and Migration Monitoring.

In Pond Watch, volunteers visit the same pond or wetland regularly throughout the year to note the presence (or absence), emergence, and behaviors of any of the main migratory species.

In Migration Monitoring, volunteers report on the timing, duration, and direction of travel of migrating dragonflies in both fall and spring, and note any additional behaviors seen, such as feeding or mating. When gathered across a wide geographic range throughout a span of years, the data from both of these citizen science projects will provide answers to questions about the frequency and timing of migration in different dragonfly species; sources, routes, and destinations of migrants; and patterns of reproduction, adult emergence, and movement among migratory dragonflies along their flight paths.

The MDP is also engaging new partners with similar interests. In 2013, the MDP began working with the Hawk Migration Association of North America, and its efforts to increase the number of resources available in Spanish has helped forge new connections and partnerships with staff of environmental and academic organizations in Mexico.

With at least 20 percent of all described odonate species in North America considered to be at risk, the MDP is also working to raise awareness about threats to these animals and increase the quality and quantity of the habitats on which they rely. In the coterminous United States alone, more than half of the 221 million acres of wetlands that existed in the 1600s have been degraded or lost under the pressures of increased settlement, farming, and industry. Managing wetlands to meet the needs of both wildlife and humans continues to be a struggle. The MDP is helping to protect at-risk invertebrates by working with state wildlife agencies to ensure that odonates are appropriately represented in State Wildlife Action Plans. Backyard habitats are part of larger watershed-wide networks that sustain the different life stages of odonates, support biodiversity in urban and urbanizing landscapes, and provide refuges and connectivity between green spaces. The MDP has developed *Backyard Ponds: Guidelines for Creating and Managing Habitat for Dragonflies and Damselflies* to help homeowners and other landowners create their own backyard refuges for odonates.

There is still much to learn about odonates, and anyone who is interested can make a real contribution to what we know about their migration, ecology, and distribution. As it enters its third year of data collection, the MDP is gaining new insights about dragonfly migration in North America, as well as new questions to be asked. With the help of an expanding network of volunteers, the MDP looks forward to solving the many riddles of dragonfly migration, while increasing protections for vulnerable dragonfly and damselfly species along the way.

The Migratory Dragonfly Partnership is working to fill the gaps in our knowledge of the life history and movements of North American dragonflies. Female wandering glider (*Pantala flavescens*), photographed by John C. Abbott.

INVERTEBRATE NOTES

Study Links Pollinator Declines and Global Malnutrition

Pollination services are important to global food security, but where are they especially critical to human health and nutrition? A recent study mapped the micronutrients supported by pollinator-dependent crops globally, then analyzed the overlap between human malnutrition and pollinator dependence. In the areas where vitamin A and iron production were most dependent upon pollination, the population was three times as likely to suffer from micronutrient deficiencies.

The authors hope that the study will suggest focal areas for research and conservation where continued pollinator declines could have a particularly devastating effect on human nutrition. (http://royalsocietypublishing.org/content/281/1794/20141799.)

Pesticide Levels Still a Concern for Aquatic Life in U.S. Waterways

A recent study by the U.S. Geological Survey of pesticide levels in U.S. rivers and streams shows that aquatic life continues to be in trouble. From 1992 to 2011, the proportion of rural and mixed-use environments in the study that exceeded aquatic-life benchmarks remained about the same, while the percentage of urban streams containing insecticides at a level harmful to aquatic life shot up to 90 percent.

The potential for adverse effects on aquatic life may be even greater than the study suggests, in that many potentially important pesticide compounds were not included in the assessment. Furthermore, recent regional studies in high-use areas indicate that it is likely that neonicotinoid insecticides and fungicides occur frequently in surface waters. (http://pubs.acs.org/doi/abs/10.1021/es5025367.)

New Books

Those of us in the Northern hemisphere may be entertaining thoughts of hibernation if it's chilly outside—just like many of our invertebrate friends. Regardless of the weather, if you're looking to curl up with a good book, why not choose one of these recent releases?

The pages of *Bees: A Natural History* (Firefly Books) brim with vivid close-up photographs of its title creatures. Author Christopher O'Toole covers a nice sample of the twenty thousand bee species found in our world, with information about bees' life history, pollination activities, and interactions with other animals. The book also includes engaging sections on bee conservation and management, humans' interactions with bees through history, bees' roles in folklore and medicine, and backyard bee science. O'Toole's tone is conversational and makes for a very pleasant read.

Beetles of Eastern North America (Princeton University Press), by entomologist Arthur V. Evans, is an impressively comprehensive field guide, describing fourteen hundred U.S. and Canadian species and enhanced by more than fifteen hundred photographs demonstrating the astounding diversity of beetles found east of the Mississippi River. The guide contains sections on identification, natural history, collecting, and geographic range for every species and family of beetle covered. Beginners and longtime enthusiasts alike will find a wealth of information to stoke their beetlemania.

Report Identifies New Drivers of Caribbean Coral Decline

Though Caribbean coral reefs have suffered a precipitous decline of more than 50 percent over the past forty years, their fate may still be within our control, according to a new report from the International Union for Conservation of Nature (IUCN). The effects of climate change are frequently cited as the cause of coral declines, but the report identifies other drivers in the Caribbean: specifically, the loss of the area's two main grazers, parrotfish and sea urchins. The absence of these species disrupts delicate coral ecosystems, resulting in unbridled algal growth that smothers reefs.

The IUCN recommends management plans to restore grazers. Combined with policies that address such additional threats as coastal pollution, tourism, and development, this could help the reefs rebound, making them more resilient in the face of the long-term pressures of climate change. (http://www.iucn.org/?16056/From-despair-to-repair-Dramatic-decline-of-Caribbean-corals-can-be-reversed.)

Pillar coral (*Dendrogyra cylindrus*). Photograph courtesy NOAA Photo Library.

STAFF PROFILE

Celeste Searles Mazzacano, Aquatic Conservation Director

What got you interested in invertebrates? When I was a kid in Texas, I would rescue insects from the municipal swimming pool, or watch transfixed as beautiful, winged adult cicadas emerged from the dull, earthbound shells of their final nymph stage. I would stop and stare as the corpse of an ant I had accidentally crushed on the sidewalk was carted off by its fellows. And when I got bored in school, I would coax a fly to visit by putting a little drop of milk on my desktop, watching as it lowered its mouthparts to sip and then cleaned itself up afterwards like a cat.

I saw all of them as tiny, perfect little aliens living among us. Who wouldn't be interested?

What's the best thing about your job? Getting to be an entomologist all the time, and being able to share my love and appreciation of these terrific animals with other people.

Who's in your family? My wife Denise, who after sixteen years is almost accustomed to me saying, "here, take this, it won't bite," as I shove an insect into her hand to hold while I photograph it. We also have three irrevocably spoiled cats.

What do you do to relax? I go insect hunting (particularly for dragonflies) of course! I also kayak, hike, camp, work out, garden, cook, walk marathons, take a lot of nature photographs, fall off of stand-up paddleboards, and play the harmonica rather badly.

What music do you have on your iPod? It's pretty eclectic, since I like variety: I have Oingo Boingo and Warren Zevon rubbing shoulders with Keb' Mo' and the Carolina Chocolate Drops, the Skatalites sharing space with Rufus Wainwright, Lyle Lovett and John Hiatt squaring off against Joan Osborne and Sheryl Crow, and the B-52s and the Pretenders mixing it up with They Might Be Giants.

Who is (or was) your environmental hero? I think the first environmental hero I became aware of when I was young was Jane Goodall. The idea of striking out alone to someplace new and spending my life observing and learning about animals was immensely appealing.

Where did you study? I got my B.S. in genetics and cell biology and earned a Ph.D. in entomology at the University of Minnesota, St. Paul.

Xerces Requests Protection for Monarch Butterfly

Populations of the monarch butterfly (*Danaus plexippus*) have declined by 90 percent in recent years. There are multiple causes of this, including loss of milkweed-rich breeding habitat due to the use of herbicides on genetically modified crops, loss and degradation of overwintering habitat in Mexico and California, and extreme weather events across its range.

In August, the Xerces Society joined renowned monarch scientist Lincoln Brower—and two other nonprofits, the Center for Biological Diversity and the Center for Food Safety—in submitting a formal petition to the U.S. Fish and Wildlife Service (USFWS) to request that the monarch be listed as "threatened" under the Endangered Species Act.

The ESA has a provision for scientists and citizens to provide information to the USFWS to help them determine what species need to be protected, and Xerces joins a long line of scientific organizations that have submitted petitions to protect animals.

Meadow blazingstar is a magnet for monarch butterflies (*Danaus plexippus*). Photograph courtesy Minnesota Native Landscapes.

Supporting Changes to U.S. Monarch Protection Strategies

In recent months, a revived energy has been brought to monarch conservation in North America, driven by discussions at the North American Leaders' Summit early in 2014 and, subsequently, President Obama issuing a memorandum directing U.S. federal government agencies to do what they can to protect the butterfly. (See the introduction to this issue of *Wings* for more detail about the President's actions and how the Xerces Society influenced them.)

Xerces has been protecting monarchs since the 1980s, placing us in a good position to help. The Society is assisting several federal agencies (including the U.S. Geological Survey and the U.S. Forest Service) in developing monarch conservation strategies. We are also partnering with the U.S. Department of Agriculture's Natural Resource Conservation Service to find ways to expand incentives for pollinator restoration on farms; working with ICF International to develop guidance on management of roadsides for the Federal Highway Administration; and collaborating with NatureServe to complete a status review of the monarch in North America.

Finally, through the Monarch Joint Venture, Xerces is helping the U.S. Fish and Wildlife Service and Mexican agencies revise the tri-national North American Monarch Conservation Plan. Our participation includes Xerces executive director, Scott Hoffman Black, being appointed as an ex officio member of the inter-agency "High Level Federal Monarch Working Group," formed under the leadership of the USFWS.

Milkweeds: A Conservation Practitioner's Guide

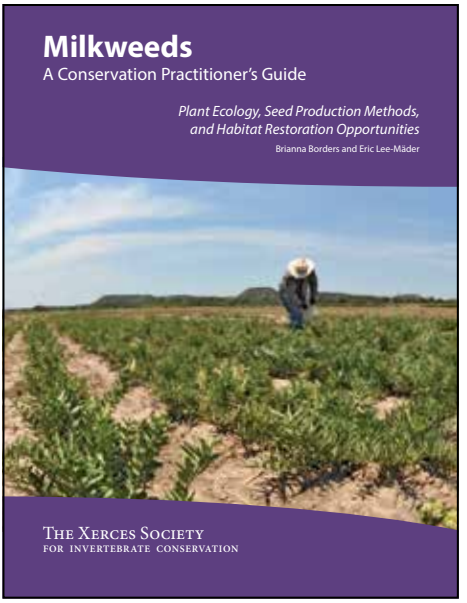
Much of the huge decline suffered by monarch butterflies has come about because milkweeds, the obligate food source for monarch caterpillars, are disappearing from our landscapes in the wake of urban development and agricultural intensification. Responding to this issue, a new guide from the Xerces Society shows how to bring back our milkweeds and restore habitat for monarch butterflies.

Milkweeds: A Conservation Practitioner's Guide is a first-of-its kind manual on large-scale milkweed seed production, nursery propagation, and field restoration of the plants. This tool provides seed producers, native plant nurseries, conservation agencies, community groups, and other organizations with the latest and most comprehensive science-based milkweed propagation and restoration methods ever compiled in a single publication.

Since 2010, Xerces' Project Milkweed has worked with the native seed industry, the USDA Natural Resources Conservation Service, and community partners to increase the availability of milkweed seed for use in the restoration of monarch butterfly habitat. These efforts have resulted in new large-scale seed production projects in several states—and nearly thirty-five million milkweed seeds available for restoration projects! With the release of this guide, we are pleased to share the knowledge and practical skills developed through this work.

The information in *Milkweeds: A Conservation Practitioner's Guide* has been gathered from interviews with native plant nurseries and seed producers, gained firsthand through Project Milkweed, and synthesized from scientific literature. This 140-page book provides conservation professionals with information about optimizing milkweed seed production methods, offers guidance on incorporating milkweeds into restoration and revegetation efforts, and highlights milkweeds' unique characteristics and value to wildlife.

Anyone who is interested in milkweeds and monarch habitat restoration will find this new guide valuable. You can download it as a free PDF from our website, www.xerces.org.



Xerces Works to Change the Use of Neonicotinoids

Studies from all over the world show that neonicotinoid insecticides are steadily poisoning our environment. Now, a new analysis by the U.S. Environmental Protection Agency presents evidence that soybean seeds treated with neonicotinoids have yields no greater than untreated seeds. Xerces is working to ensure that this accumulated body of research is considered by policy makers and that we move to more ecologically sound methods of pest control.

We are proud to have been a part of many efforts around the country to protect pollinators from harmful pesticides. We have helped people in fourteen states, providing the scientific and technical support they needed to succeed. In Reno, Nevada, for example, we assisted community members to create twenty-seven pesticide-free parks; similarly, we helped with city-wide neonicotinoid prohibitions that have been adopted in Seattle and Spokane, Washington; in Shorewood, Minnesota; and in Eugene, Oregon. In addition, the Xerces Society served on Oregon's Task Force on Pollinator Health, which recently delivered its recommendations to the state legislature.

Saving Freshwater Mussels

Last summer, Xerces staff spent two days working with local volunteers to rescue hundreds of native freshwater floater mussels (genus *Anodonta*) from Crystal Springs Creek in Portland's Westmoreland Park. The creek was to be restored and the mussels were moved out of the way so the creek could be

Volunteers search for freshwater mussels during relocation monitoring. Photograph by Dick Dewey.

de-watered (temporarily put through a pipe) and reshaped by machinery. The mussels were relocated to an adjacent upstream stretch of the creek; five hundred of them were given numbered tags to facilitate subsequent monitoring.

Xerces aquatic program staff Celeste Mazzacano and Michele Blackburn, together with volunteers from the Crystal Springs Partnership, returned to the creek in September to survey the restored reach. Their goal was to establish the baseline for recolonization, and to search the area for as many tagged mussels as they could find. The survey suggests that more than 95 percent of the relocated mussels are thriving.

The de-watering of the project area did result in the death of any mussels remaining in the empty creekbed; even so, two native floaters like those that had been relocated were found in the restored section of the creek—an adult at the downstream end of the restored reach, and a thumbnail-sized juvenile at the upstream end.

Oil in Our Oceans: New Report Reviews Impacts of Oil Spills

In April 2010, an explosion on the *Deepwater Horizon* drilling rig resulted in a ruptured wellhead five thousand feet below the surface of the Gulf of Mexico. Crude oil spewed into the depths for nearly three months, and at least 193 million gallons of oil were released.

After such an incident, news broadcasts and newspapers show us photographs of oiled birds and struggling mammals, but the damage goes much deeper, impacting the invertebrates that are the basic building blocks of our marine environment. Oil spills have affected—and will continue to affect—invertebrates and their habitats across the globe. There is no question that spilled oil is highly toxic to marine invertebrates and that this toxicity is long-lasting, but, because of the extreme di-

versity of marine invertebrates and the relative lack of research, we still know little about the ultimate ecosystem-wide impacts of these events.

The Xerces Society has released a new scientific report, *Oil in Our Oceans: A Review of Impacts of Oil Spills on Marine Invertebrates*, to help fill this knowledge gap. Exploring the effects of oil spills on marine invertebrates, from corals and zooplankton to crabs and oysters, the report clearly establishes that an oil spill causes immediate harm to invertebrate populations and continues affecting wildlife for years, even decades, after the cleanup crews have left. The report reviews the significance of invertebrates to the marine ecosystem and commercial fisheries, identifies the impacts of oil spills, and makes recommendations on how to reduce these impacts. It includes a section on the *Deepwater Horizon*, and a series of profiles of species of particular concern in the Gulf of Mexico.

Download a free PDF of the report from our website, www.xerces.org.

Planned Giving: Your Legacy for Invertebrates

A charitable bequest is one of the simplest ways to provide continuing support to the Xerces Society beyond your lifetime. By making a planned gift through your will or estate, you can create a personal legacy that will provide lasting benefit for the conservation of invertebrates and help preserve these essential creatures for future generations.

We highly recommend that you discuss your planned giving options with your attorney or financial adviser in order to choose a gift that works best for you and your family. If you would like to inform us of your plans, or if you have further questions, please send an email to suzanne@xerces.org, or call us at 855-232-6639.

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For information about membership and our conservation programs for native pollinators, endangered species, and aquatic invertebrates, contact us:

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Dwarfed by its surroundings—as well as by its antennae—this nymph of a dragon-headed katydid (*Lesina intermedia*), a Malaysian species, was reared in captivity at the San Diego Zoo. Photograph copyright San Diego Zoo.

A $35 per year Xerces Society membership includes a subscription to *Wings*.

On the cover: One small population of the Lord Howe Island stick insect (*Dryococelus australis*) is known to survive in the wild. An international group of zoos is developing a breeding program to ensure a future for this species; the San Diego Zoo is the lone partner in the United States. Photograph by Rohan Cleave, Melbourne Zoo.