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CHAPTER 1

A SLIVER OF CREATION

After I started my job at North Carolina State University in summer 2001, I toured the habitats of two of the last known populations of the St. Francis' Satyr (*Neonympha mitchellii francisci*), located at Fort Bragg army installation in southern North Carolina. I traveled through pinewoods on rutted dirt roads to visit a just-discovered population where the butterfly was easy to spot. This marked the beginning of my research on the St. Francis' Satyr. I had some early successes and found a few new populations. This inspired me to continue my search for undiscovered populations in remote wetlands at Fort Bragg. Every summer since, I have trudged through swamps and broken through walls of shrubs and vines. For the most part, my effort has been in vain. My challenges in finding new populations of St. Francis' Satyr were emblematic of the science and the search for the rarest butterfly that lay before me.

The butterflies that are the subject of this book represent just a sliver of creation. If we were at a dinner party and I asked you to think of a rare animal, what would come to mind? I would expect to hear names of animals such as the Giant Panda (*Ailuropoda melanoleuca*), the Black Rhinoceros (*Diceros bicornis*), or the Northern Spotted Owl (*Strix occidentalis caurina*). Like the butterflies I study, these animals are rare and threatened. Unlike the rarest butterflies, they are large, charismatic vertebrates. These animals are also different in a way that may not be immediately apparent (at least it was not to me): they are not nearly as rare as the rarest butterfly.

Rare butterflies make up a small number of earth's nineteen thousand or so butterfly species, and butterflies in general make up a small fraction of the estimated 5.5 million insect species. Relative to other insects, butterflies hold an advantage: they provide us clearer avenues for understanding general threats to biodiversity and pathways to conservation. We know much more about butterflies—their diversity, ecology, and evolution—than any other group of insect. We also know more about the size of their populations and about the area of their ranges—which means there are data to support my assessment of rarity.

Imagine the increasingly likely scenario in which you could corral all the living adults of all the very rarest butterflies and then hold them in your hands. If, for example, you could hold the entire world population of adult Schaus' Swallowtail (*Heraclides aristodemus ponceanus*) butterflies, its weight would be roughly six ounces. The collective weight of all individuals of the five rarest butterflies that I discuss in this book would weigh only three pounds five ounces—as much as one panda's paw. And, in contrast to these tiny populations, there are billions of individuals of such common butterflies as Painted Ladies (*Vanessa cardui*) and Small Cabbage Whites (*Pieris rapae*).

The rarest butterflies have not always been rare. Some were very abundant until the last few decades; it is likely that their numbers dropped from millions to thousands. For other rare butterflies, it is impossible to estimate their historical abundance. However, we do know the historic range of their habitats and from that we can extrapolate high abundances. Global habitat loss and climate change have relegated each species to minuscule land parcels, areas as small as a single golf course or even a football field. I have found rare butterflies in unexpected places, their populations restricted to artillery ranges or beaches or backyards.

In every year that I worked and for every species that I studied, I wondered whether I would see the last of these butterflies. The rarest butterflies fly dangerously close to extinction. Numbers are so low that I feared small changes in the area of a forest, the saturation of a wetland, or the level of the ocean would wipe out an entire species. Their numbers and ranges are so small and the threats are so high that my encounter with the last butterfly was a real possibility.

I have staked much of my professional career on efforts to reverse butterfly population declines. There remains some glimmer of hope in prospects for species recovery. In this book, I recount stories about my and others' progress in understanding the biology and conservation of the rarest butterflies in the world. Moreover, I argue that they stand among the poster animals for the loss of biodiversity and the future of conservation. The rarest butterflies may seem at first a surprising or even undeserving part of this group. They are a small set of virtually unknown animals that may appear more idiosyncratic than emblematic of environmental biology and conservation. Yet, viewed in a deeper way, the rarest butterflies provide a unique lens into growing concerns and problems: the loss of

biodiversity on our planet and the challenges associated with conserving species in peril.

BUTTERFLIES AND GLOBAL CHANGE

The rarest butterflies suffer from headline-grabbing environmental catastrophes, such as habitat loss, climate change, environmental toxins, and invasive species. Often, these threats act in concert to reduce their populations. The rarest butterflies—and, I argue, much of the diversity of life on earth—are confronted simultaneously with multiple threats that accelerate decline.

Even when habitats are viewed as protected, they can be lost from the perspective of the rarest butterflies. This is a key to understanding why the rarest butterflies are so rare. Like the fairy-tale character Goldilocks, the rarest butterflies require conditions that are *just right*. Some butterflies live in habitats maintained naturally by disturbance such as fire. Too much fire over too broad a region will incinerate populations. Too little fire will cause butterfly habitat to disappear through natural processes of succession, causing their host plant (defined as the plant or plants that caterpillars live on and eat) to die. By stopping fire, draining wetlands, and stabilizing beaches, people suspend natural environmental change and upset a delicate balance. Conditions are no longer *just right*. These insidious threats, cast against a backdrop of major global changes, are slowly eroding the populations that remain.

One thing that distinguishes the rare butterflies from other rare species is that they have specialized environmental requirements that exist in places where people also want to be. In some cases, people use land in ways that are incompatible with the habitat required by the butterflies. Some butterfly ranges have

the bad luck of being located near dense urban development or large monocrop fields. In other cases, the expanding footprint of people has helped to conserve the rarest butterflies. The St. Francis' Satyr, for example, lives only on a mostly undeveloped army base. The message here is that there can be win-win scenarios for people and butterflies.

THE SCOPE OF MY SEARCH

Is it even possible to identify *the single rarest butterfly* in the world? As I attempted to do so, I wrestled with issues that arise in the conservation of all plants and animals about how to define what is rare. Many, many butterflies are rare, a number that is too great to cover in many book volumes, let alone in one book. The growing number of rare butterflies is an inevitable consequence of global environmental change. I narrowed my scope to those that I found to be the rarest. As I will discuss, I consulted references worldwide about butterfly population sizes. I failed to identify a species outside of the United States that, after considering range-wide population estimates, was rarer than the rarest species I identified within the United States. In part, the list also reflects my personal journey, restricted mainly to North America. Although others might dispute my assessment and ranking of the rarest butterflies, the conservation needs of each species I describe are not in doubt.

To guide my search, I drew heavily on lists of butterfly species that have garnered formal recognition as conservation priorities. As people have increased their attention to butterflies and their rarity, political processes have evolved to favor butterfly protection. As I looked back at the history of butterfly conservation, I saw plainly that the enactment of the US Endangered Species Act (ESA) in 1973 was a watershed. The first butterflies

appeared on this list in 1976. Species are recognized, or listed, as either *endangered* (in imminent danger of extinction) or *threatened* (in danger of becoming endangered).

While the Endangered Species Act applies to the United States, the International Union for Conservation of Nature (IUCN) maintains the most prominent worldwide list of species that have disappeared or are threatened with extinction: the IUCN Red List of Threatened Species. The IUCN began to document the conservation status of butterflies in 1983. I was attracted to the Red List because it adopted *quantitative* scales of vulnerability that included population size, range, and change over time. Another international list was compiled, beginning in 1976, pursuant to the Convention on International Trade in Endangered Species (CITES), an international agreement designed to protect threatened species, including rare butterflies. This list identified rare species in most danger of being moved by people across national borders; prominent species on the list include tigers and rhinos, the hides, bones, and/or horns of which can be transported across borders. Although less attention is given to butterflies, CITES recognizes species that might be the targets of butterfly collectors.

I also consulted results of efforts to monitor butterfly populations, especially over the area of states or nations. The world's most intense and longest-running butterfly monitoring program is the United Kingdom Butterfly Monitoring Scheme (UKBMS). Others include South Africa's intensive records of long-term diversity and status of butterflies, and the annual butterfly counts of the North American Butterfly Association (NABA). Even after I consulted these resources, I recognized that there were surely other rare butterflies awaiting discovery. Those were beyond my purview for this book.

I used these resources to narrow the list of the world's rarest butterflies. I gave a great deal of thought into how to assess rarity. Is the rarest butterfly the one with the smallest number of individuals that remain? Well-established scientific theory and observation have shown that biological and genetic factors can drive numbers in small populations down further. Or is the rarest butterfly the species that ranges globally over the smallest area, measured in the tens of acres and often in remote locations? A small area exposes rare species to large and rapid decline. Long-term changes, such as habitat conversion to cities or fields, and short-term changes to the physical environment, such as drought, can change a butterfly's environment quickly throughout its range. Perhaps the rarest butterfly species is the one whose population is experiencing the most precipitous decline. Some of the rarest butterflies flew over large regions until recently, areas the size of half a state or province. In some instances, scientists ignored them until populations declined to the last butterfly. Should I have considered how novel a butterfly is in the context of all butterflies and of life on earth? A lone and unique lineage may have greater value to genetic diversity and future evolution.

As there was no single standard, I chose as my criterion the total number of individuals of the species left in the world. This measure was the most transparent and the most directly linked to conservation threat. When I began my search, I expected that I could find a scientific study reporting total population sizes for each butterfly species purportedly among the rarest. In practice, scientists adopted a variety of methods to derive butterfly population numbers. For one example, scientists counted the number of Eastern North American Monarchs (*Danaus plexippus plexippus*) on a few trees in the butterflies'

overwintering grounds in Mexico and then applied that density to the few hectares they cover there. Others caught the world's remaining Schaus' Swallowtail females (one measure) and propagated them in a lab for release into the wild (another measure). One thing I enjoyed about writing this book was the opportunity to distill the results of different methods to numbers that I could compare.

BUTTERFLY LIFE CYCLE

A butterfly passes through several stages as it completes its life cycle from egg to adult. Caterpillars (also called larvae) grow in about five stages; each stage is called an instar. When an instar outgrows its skin, or exoskeleton, it sheds it (molts) and passes to the next instar. After its final molt, it is left with a hardened outer shell, or chrysalis. The chrysalis contains the inactive larval form (a pupa) that transforms into an adult via metamorphosis. Butterflies can live through one or more generations each year. They can enter an inactive state, or diapause, to avoid harsh conditions such as winter weather. Different species diapause at different life stages, and the length of time a species spends at any stage is variable. For example, whereas adult, overwintering Monarchs can live for six months, adult St. Francis' Satyrs live for only four days.

In this book, I tell the stories of eight species and subspecies of butterflies. I have organized the book by chapter, covering the six rare butterflies in sequence from the most common (Bay Checkerspot, *Euphydryas editha bayensis*) to the rarest (Schaus' Swallowtail, *Heraclides aristodemus ponceanus*); following these

are chapters on an extinct subspecies and a common subspecies. Figure 1.1A shows the large range in numbers across all eight species and subspecies. For a given species, all of the butterflies might or might not have lived in one place. To a conservation biologist, a population encompasses the area in which all the individuals of a species can interact with one another. One population is geographically separated from others. As a general rule, the total number of individual butterflies correlates with the number of populations. For example, the Fender's Blue (*Icaricia icarioides fenderi*) occurs in more populations than and at higher abundances than the Schaus' Swallowtail. The situation is different with the Bay Checkerspot and the Eastern North American Monarch, which are the most abundant butterflies I discuss, but which live in one population (Figure 1.1B). Among the eight butterflies I looked into, the number of populations ranged from one to thirty-six, and my search turned up some butterflies that occupied few places but were, in fact, very numerous relative to the others.

SUBSPECIES

Scientists have classified most of the butterflies featured in this book not as species but as subspecies. A species, by definition, is the group of individuals that can interbreed only with one another. The subspecies category recognizes that some individuals of the same species are so geographically isolated—by, for example, distance or mountain barriers—that they will never have the opportunity to interbreed. Unlike separate species, members of different subspecies could, if brought together, interbreed. Because they are separated by such large distances, different subspecies may differ in their color, form, or behavior.

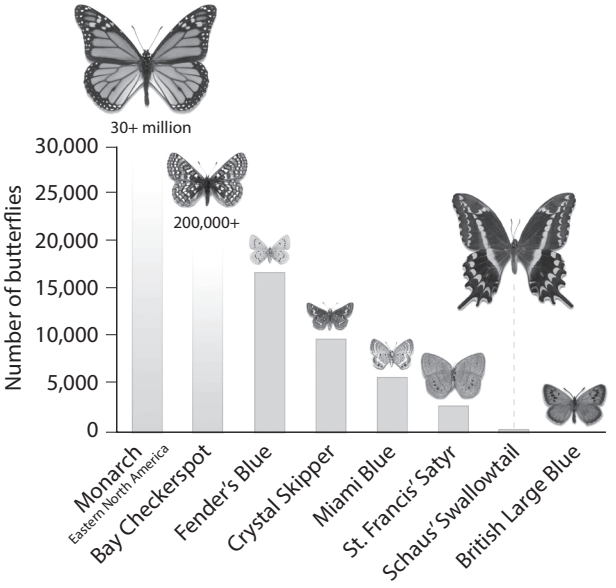

FIGURE 1.1A. Worldwide number of butterflies of each species or subspecies highlighted in this book. I explain the data and give sources in each chapter.

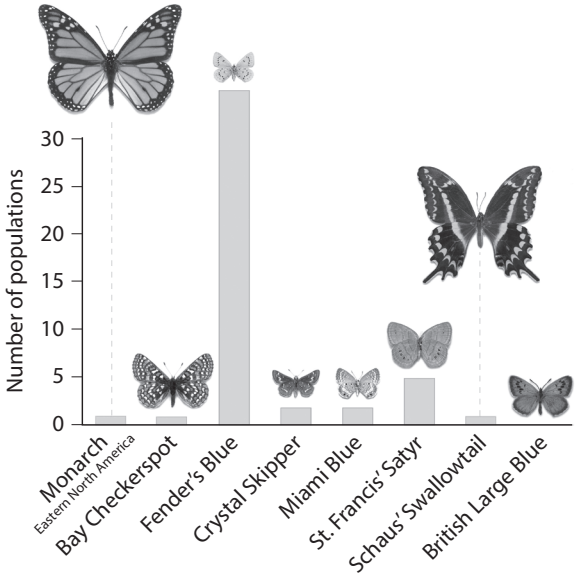

FIGURE 1.1B. Worldwide number of populations or metapopulations of each species or subspecies of butterfly. I explain the data and give sources in each chapter.

One butterfly I studied in North Carolina, the St. Francis' Satyr, illustrates the challenges and consequences of recognizing subspecies. At first appearance, the St. Francis' Satyr looks identical to a related subspecies, the Mitchell's Satyr (*Neonympha mitchellii mitchellii*), which was until recently found only in Michigan (small populations have turned up in Alabama, Mississippi, and Virginia). The scientists who first discovered the St. Francis' Satyr named it a subspecies because of its distance from the other subspecies and subtle differences in appearance. Does this designation hold up when evaluated by other standards? To learn more, I collaborated with a graduate student, Chris Hamm, who gathered samples and tested how closely related the populations are to one another. Chris conducted genetic analyses of six short segments of DNA. His analysis revealed that the Mitchell's Satyr and the St. Francis' Satyr are different, perhaps even different species.

I included subspecies in my search because they are significant in conservation work. Subspecies are important in four ways. First, subspecies and not species represent more fully the variation of life on earth. Second, a subspecies' decline in a region is indicative of broader environmental degradation. Third, subspecies play an irreplaceable role in ecological systems. Fourth, one subspecies can provide a source to replace another subspecies of the same species if one goes extinct.

For example, one subspecies of Large Blue butterfly that occurred in England, the British Large Blue (*Maculinea arion eutyphron*), went extinct before scientists understood how to conserve it. With new knowledge in hand, they were able to introduce another subspecies of Large Blue (*Maculinea arion arion*), from Sweden. It was successfully established. Although the genetic variation carried in the British subspecies was lost forever, the Swedish subspecies could for the most part fill the

British Large Blue's ecological role. With this in mind, I chose to focus on subspecies because of their need for conservation and their relevance to ecological systems. For the remainder of the book, I sometimes use the term *species* for simplicity, whether I am talking about species or subspecies.

FRAGILE OR RESILIENT?

Despite the threats faced by the rarest butterflies, these insects persist. Their persistence embodies a prominent question in conservation: Is nature fragile or resilient in response to environmental change? Some see resilience in nature, including in the recovery of some large animals and in the apparent functioning of ecosystems after elimination of some animal and plant species. Those who see fragility can point to mounting extinctions of birds, mammals, and other wildlife, and broader degradation of ecological systems. The rarest butterflies provide an intriguing lens through which to examine this dichotomy.

Their delicate wings and small size suggest fragility. I often use the most important item of research equipment in my toolbox, a butterfly net, to brush over vegetation and instigate butterfly flight. At times I use my net to capture butterflies, so I can mark their wings and track their populations, or to catch females that will lay eggs for captive propagation, or to sample tiny wing fragments for genetic analyses. When I do this carefully, I find that individual butterflies are resilient to capture and handling. If I capture them improperly, however, I can loosen scales or bend wings. Their wings mirror a fragility in natural environments that is a more urgent threat to their survival. All the rarest butterflies have declined and are declining rapidly. Each is slipping away.

Despite their fragility, I am inspired in my research and conservation by signs of resilience. I am heartened by the possibility of restoration and recovery. One of these signs is the persistence of many of the rarest butterflies in unnatural places. A theme that repeats across chapters is that activities of people can sometimes replace natural disturbances (fire, for example) that they have otherwise reduced or eliminated in butterfly habitat.

There is not a strict dichotomy between fragility and resilience of the rarest butterflies. I find compelling a story of William Henry Edwards, a nineteenth-century lepidopterist (a person who studies or collects butterflies or moths, which belong to the scientific order Lepidoptera). He lived along the Kanawha River in West Virginia. A swamp near Edwards's home had a healthy population of Baltimore Checkerspot (*Euphydryas phaeton*) butterflies. Local coal companies sought to improve river transportation, and to do so they made waterways deeper and wider and created a series of locks and dams that flooded the landscape. Consequently, they exterminated the fragile population of the Baltimore Checkerspot. Keen to restore this butterfly's population, Edwards waited until the floods receded. He then propagated Baltimore Checkerspots from caterpillars to adults and released them back into the river valley. The population flourished.

I find that the rarest butterflies embody a more fundamental dichotomy between the gloom and hope that I share with others involved in modern conservation efforts. On the front lines of conservation, the signs of decline among rare butterflies are everywhere, and it is easy to despair. Yet, as a conservation biologist, I am optimistic and hopeful that the demands of people can be reconciled with the needs of nature. The rarest butterflies have taught me how people are causing environmental harm,

but my research has also led to discoveries that expand possibilities for healing nature.

Even if resilient, the rarest butterflies will not recover immediately. It grates on me when I read opinions written by politicians or skeptical conservationists who see failure when a butterfly that receives legal protection as endangered, accompanied by investment of time and money in conservation, does not recover in five years or a decade. The rarest butterflies have arrived near extinction over decades or centuries of decline. Is it then surprising that it could take just as long to see them recover? By unraveling their biology, I hope to learn enough about the rarest butterflies and their ecosystems to restore them. In this book, I contemplate the fragility and resilience of nature as it tells the story of the loss and potential recovery of the rarest butterflies.

AVERTING EXTINCTION

The most basic goal of my research is to pull the rarest butterflies back from the brink of extinction. There are metrics other than extinction for measuring the effects of changing environments on butterflies. However, once they have fallen to ultimate extinction, conservation is irrelevant to them, and people have reduced earth's biodiversity. As I tell the stories of individual rare butterfly species, I will be relating what scientists are learning about recovering their populations before they reach this irreversible fate. Yet, for each of the rarest butterfly species in the world, extinction remains a very real possibility.

As far as we know, only three butterfly species and a dozen butterfly subspecies have ever gone extinct. This apparently low number might be because butterflies have weathered global environmental change. More likely it is because undiscovered

butterflies have gone extinct without notice. One butterfly species that went extinct was the Xerces Blue (*Glaucopsyche xerces*). It inhabited sand dunes in what is now San Francisco's Sunset District. The gold rush that began in the late 1840s caused the city to fill with people. By 1875, biologists recognized the Xerces Blue's decline. Herman Behr, a curator of entomology at the California Academy of Sciences, wrote, "The locality where it used to be found is converted into building lots, and between German chickens and Irish hogs no insect can exist besides louse and flea." By 1941 the Xerces Blue was extinct.

Now the only place to see the Xerces Blue is in museum collections. My search for it took me to the McGuire Center for Lepidoptera and Biodiversity at the University of Florida in Gainesville. I asked collections manager Andy Warren to show me a pinned specimen of the Xerces Blue. I gasped when he pulled out a drawer containing more than one hundred specimens collected seventy-five or more years ago. There was a time in some people's living memory when Xerces Blue was not so rare.

Scientists presume two other butterfly species are extinct. Both occurred in South Africa. The Mbashe River Buff (*Deloneura immaculata*) was collected only three times ever, all in the mid-nineteenth century on the Eastern Cape. Morant's Blue (*Lepidochrysops hypopolia*) was also collected three times, in the 1870s, in two different regions. Nobody has observed a single individual of either since then.

I include a chapter on one extinct subspecies, the British Large Blue. Beginning in the nineteenth century, it declined in abundance for over one hundred years. Scientists learned the key details of the butterfly's biology and conservation just as it went extinct. The British Large Blue exemplifies how declines and recovery of the rarest butterflies require understanding of

the very subtle and particular biology of butterflies. I include this chapter because it carries this and other lessons about the conservation and science of the rare butterflies that still exist.

THE RAREST BUTTERFLIES AND BEYOND

Throughout my search, three questions haunted me. First, for each butterfly: What can I or others do to reverse course and prevent impending extinction? Second, stepping back from each butterfly: Can general lessons learned from one or a few butterflies be applied to other butterflies and other animals and plants? Third, the hardest question of all: Are there compelling reasons to save the rarest butterflies in the world—or should we put our efforts elsewhere?

I have discovered that the rarest butterflies in the world are emblematic of the consequences of a range of global environmental changes and of the modern challenges in biodiversity conservation more generally. Throughout the book, I contemplate and clarify the value of species and the meaning of their potential loss. By stringing together observations that connect biology to global change to conservation, I have come to know with more intimacy the diversity of life on earth and its need for protection.

Although my focus is on very rare butterflies, even the most common species are susceptible to precipitous population declines. For this reason, I have included a chapter about the Monarch. It shares with the rarest butterflies threats from all environmental changes, and because of this, it too is becoming rarer.

I will admit that I included the Monarch with some reluctance. Anyone reading this book will know the Monarch. For many people, any familiarity with butterfly biology is limited

to a knowledge of Monarchs. When I have given talks about rare butterflies, I have fielded questions about why these species cannot do what Monarchs do. I once talked about the destruction of a rare butterfly's habitat. A student asked, "Why don't the rarest butterflies just migrate to better places, far away from danger?" In their migration and in other ways, Monarchs are unique, and they do not provide a good model for other butterflies. Unlike Monarchs, which are widely distributed and familiar, the rarest butterflies are unknown to nearly everyone. Still, the Monarch is declining. Scientists are working to understand the causes, so that the Monarch doesn't end up as one of the rarest butterflies. Perhaps one day the knowledge others and I acquire about recovery of the rarest butterflies will inform conservation of now common but declining species such as Monarchs.

In contrast to the prospects for the rarest butterflies in this book, the idea of the last butterfly in the global sense seems preposterous. Or I thought so, until I read an important paper by Stanford University professor Rodolfo Dirzo and colleagues. These researchers reviewed the world's half-century-long records of insect abundances and discovered that butterflies and moths as a group lost on average a third of their numbers (Figure 1.2). This includes measures of common and rare species. At this rate, the last butterfly would be only a few decades off. Clearly, this trend will not continue downward until 100 percent of all butterflies are lost. However, it speaks to the sustained loss of many rare and common butterflies. I was attracted to this paper because of its inclusion of butterflies. As I studied the article's key graphic, I was astonished to learn that all other insects had declined even faster than butterflies. The study of individual butterfly species has such a rich and extensive history that, as I suspected, the analysis included many more members

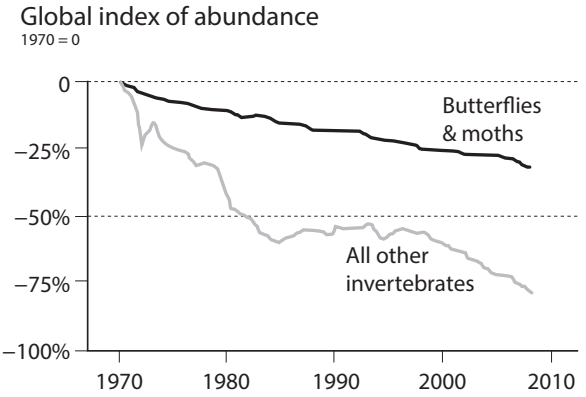

FIGURE 1.2. Change in abundance of invertebrates worldwide since 1970. Adapted from Dirzo et al. 2014, who conducted a review of all long-term studies of invertebrate populations.

of the order Lepidoptera than all other insects combined. It follows that the correlation between butterflies and other insects supports the use of butterflies as a broader indicator of biodiversity decline. Global analyses like this one indicate that the rare and declining butterflies serve as the new canaries in the coal mine for biodiversity loss.

By 1970, the starting point for records studied by Dirzo et al., the rarest butterflies I write about had already traveled downward beyond the low points shown on the graph (Figure 1.2) of 30 percent loss for all butterflies (common or rare) and 80 percent loss for other insects. Now that we have arrived at this point, what can be done? For the rest of the book, I try to answer this question for each of the rarest butterflies, highlighting new advances in science and conservation. Perhaps these answers can be used to halt or reverse the downward trend for the rarest butterflies and, ultimately, for other insect species.

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NOTE: Page numbers followed by *f* indicate a figure.