FUNDAMENTALS OF
CONSERVATION BIOLOGY
FOURTH EDITION

"This book is about hope in the face of forces that would degrade our world. This book is about the rich tapestry of life that shares our world now and about how we can maintain it, sometimes in places that we protect and set aside, more often in places where we share the lands and waters with a wide range of other species."

For more than 30 years, *Fundamentals of Conservation Biology* has been a valued mainstay of the literature, serving both to introduce new students to this ever-changing topic, and to provide an essential resource for academics and researchers working in the discipline. In the decade since the publication of the third edition, concerns about humanity's efforts to conserve the natural world have only grown deeper, as new threats to biodiversity continue to emerge.

This fourth edition has taken into account a vast new literature, and boasts nearly a thousand new references as a result. By embracing new theory and practice and documenting many examples of both conservation successes and the hard lessons of real-world "wicked" environmental problems, *Fundamentals of Conservation Biology* remains a vital resource for biologists, conservationists, ecologists, environmentalists, and others.

Malcolm L. Hunter, Jr. is the Libra Professor of Conservation Biology at the University of Maine and the former President of the Society for Conservation Biology.

James P. Gibbs is Distinguished Professor of Conservation Biology at the State University of New York College of Environmental Science and Forestry, and Conservation Scientist at the Galapagos Conservancy.

Viorel D. Popescu is Assistant Professor of Conservation Biology at Ohio University, Athens and Research Associate at University of Bucharest's Center for Environmental Research, Romania.

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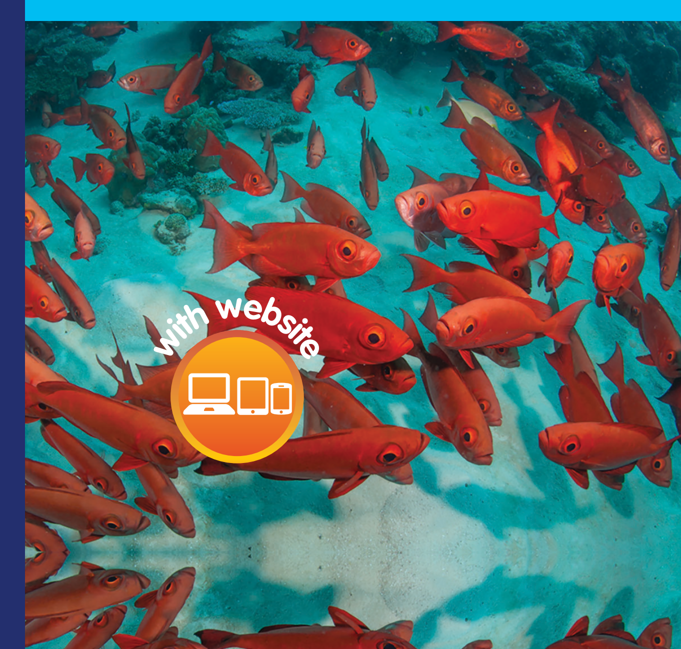
CONSERVATION BIOLOGY

MALCOLM L. HUNTER, Jr. • JAMES P. GIBBS • VIOREL D. POPESCU



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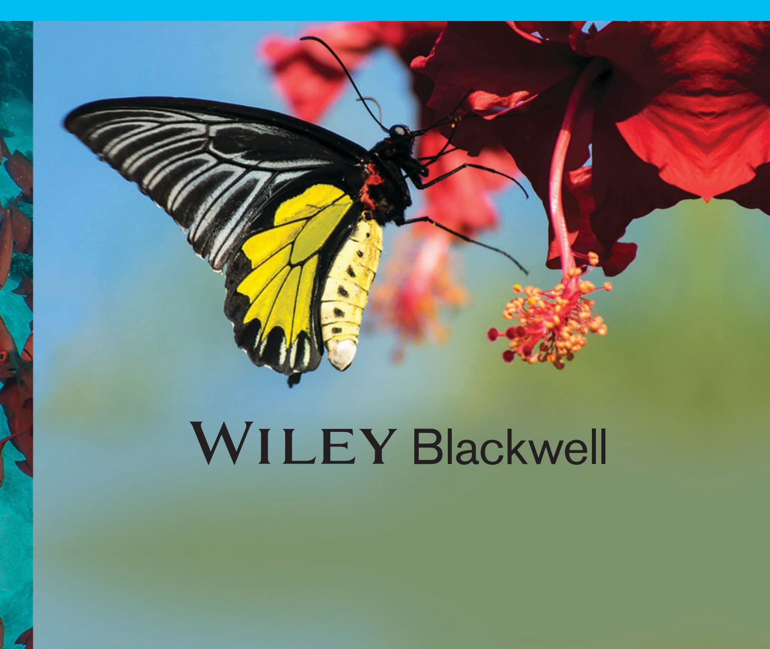

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Fundamentals of Conservation Biology

For Aram J.K. Calhoun, who inspires us with her delight in the natural world and dedication to conservation.

For Kathleen E. (Cassie) and Harold C. Gibbs, who inspired many to know and care for life on Earth.

For Tavi B. Popescu, whose wonder about the natural world gives us optimism about the next generation of the Earth's stewards.

Fundamentals of Conservation Biology

Fourth Edition

Malcolm L. Hunter, Jr.
University of Maine
Orono, USA

James P. Gibbs
State University of New York
College of Environmental Science and Forestry
Syracuse, USA

Viorel D. Popescu
Ohio University
Athens, USA

WILEY Blackwell

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About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/Conservation-Biology4e

The website includes:

Figures from the book for downloading

Preface

11:15 P.M. 20 June 1990 I'm not used to being this hot so late at night. I don't know the sounds coming through the window . . . crickets? . . . frogs? . . . a wheezing air-conditioning system? I don't know what to do.

I'm in a dorm at the University of Florida; the fourth meeting of the Society for Conservation Biology has just ended; I'm sifting through various conversations of the last 4 days. I wonder if I should postpone my plans to write a sequel to my book on managing forests for biodiversity – a sequel that would focus specifically on tropical forests. At the meeting I've discovered that professors are using my book for a much broader range of conservation courses than I ever anticipated and that tells me that there is a niche to be filled.

Apparently various multiauthored books on conservation biology topics are not filling the need for a basic text. Perhaps I should add a brick to the foundation of the discipline before pursuing a more specific project. Now if I can rough out an outline before I get too sleepy . . .

27 August 1993 Over 3 years later and I have just finished the first draft. Actually the writing went reasonably quickly (I did not begin in earnest until May of 1992) because I chose a sort of stream-of-consciousness approach in which I wrote only what I knew or thought I knew. Now I look forward to spending the next several months combing the literature, correcting, refining, and updating this draft. It might seem that this approach would make it easier to convey my original thinking about conservation biology as opposed to reporting on everyone else's thinking. Perhaps so, but I claim no truly original thoughts. I tend to think each person is no more than a unique melting pot for a vast community of ideas.

24 August 1994 Sifting through the literature of conservation biology has been great fun, although it has entailed some difficult choices. If many of my readers will be North American, should I keep things familiar and easy by illustrating general principles with redwoods, bald eagles, and well-known foreign species like tigers? Or should I try to open some vistas by describing fynbos, huias, and thylacines? Many years of working abroad predispose me toward the latter approach, but I have curbed this temptation to some degree, partly to save the space it would take to describe the fynbos, and partly because I have tried to select literature that will be reasonably accessible.

As I enter the final stages of production I often think about my readers and how they will use this book. My primary audience is students who have some background in biology and ecology but who have not taken a previous conservation biology course. I also hope to reach some general-interest readers and have tried to keep the prose fairly lively so that they can manage at least half an hour of bedtime reading before dozing off.

This is an opportune place to explain two features of the book. First you will note that there are almost no scientific names in the text; they are all in a separate list of scientific names, which also constitutes an index to all the species mentioned in the text. Furthermore, the literature cited section constitutes an index to authors, because after each citation the pages where it is cited are listed.

27 December 1994 Two more days before the book goes out to copy-editing, and it is time to start listing all the scores of people who have helped in an acknowledgment section. I particularly want to thank Andrea Sulzer, the friend and artist who illustrated the book; the Department of Wildlife Ecology of the University of Maine, where a relationship that began in 1970 has recently led to a professorial chair endowed by the Libra Foundation; and Aram Calhoun who has shared all but a month of our marriage with this book. Finally a special thanks to everyone who buys this book for all its royalties are allocated to a fund to support conservation students from developing countries.

Second edition: January 26, 2001 Before undertaking this second edition I was rather dreading the prospect of replowing old ground, tearing apart my first edition and putting it back together again. In hindsight, the last 9 months of sorting through the conservation biology literature have been rather enjoyable, especially after I realized that it was okay to be selective in my reading. With 651 new references there is a lot of fresh material to chew on here; most of it is very recent (my last trip to the library was this morning) although I have also added some older papers from the "classical period" of conservation biology (the 1980s). A new glossary and many new illustrations are also prominent features of this edition.

Third edition: 15 May 2006 I am returning home from a 4-month sabbatical in Australia, where weekends were spiced with pursuing wombats, whale sharks, and lyre birds, just in time to work on the production phase of this book. Two years ago when I decided to invite a coauthor to join me it took about 10 seconds to identify James Gibbs and, the next day, it took even less time for him to accept. I have worked with James for 25 years, since he was a new student at the University of Maine and I was a new professor, and it has always been a pleasure. James' expertise with genetics and population biology, complementary experiences with field conservation projects around the world, and his willingness to dive into the social sciences was just what was needed to strengthen this edition.

Another salient feature of this edition is a strong shift to color images. Finding illustrations for this edition has been an enjoyable challenge and we are grateful to the many people whose works appear here.

Of course the substance of revising any textbook lies in new literature, and the field of conservation biology remains vigorous in this regard. The 762 new references added here are just a small sample of the high-quality research that characterizes the discipline. We have also added three new case studies, holding back somewhat because we think case studies should largely be generated and presented by faculty and students based on their own experiences and interests. Overall the book is 6% longer than the last edition as measured by the number of words, but 50 pages shorter because of more compact formatting.

As with earlier editions, the royalties are going into a fund to support conservation students from developing countries, most recently the fieldwork of a student from Argentina studying cavity-nesting birds in the Andes for her dissertation. In time the royalties will be sufficient for an endowed, perennial source of support for similar aspiring conservationists.

Fourth edition: 31 December 2019 New Year's Eve and a steady snow is luring me outdoors to celebrate a thirtieth wedding anniversary, but first I need to draft the last few new words for our fourth edition. The most conspicuous new feature is the addition of Viorel Popescu as an author, continuing a tradition of extending academic lineages, given that Viorel earned graduate degrees with both James and me. Undertaking a collaboration like this requires considerable trust and James and I knew that Viorel had the talent and commitment to make a huge contribution to the book, leading the revision of four key chapters and carefully reviewing all of the chapters. Furthermore, he brought to the table many new perspectives as a native of another part of the world – Romania – where he remains active in conservation at many levels.

With a long interval since the third edition there has been a vast new literature to comb through, and it was challenging to limit the new additions to "only" 950 new references. The conservation literature has expanded dramatically, by embracing new theory and methods, and documenting many examples of both conservation successes, and the hard lessons of real-world "wicked" environmental problems. For example, climate change was a mere hypothesis when this book began; now it is a defining reality, the focus of one chapter, and an underlying thread in many others. Many other chapters have been reformulated to reflect the ever-changing landscape of conservation biology, among them "Conservation near People" that represents a new shift in attention to the privately owned lands where much of the future of biodiversity conservation will play out. Similarly, we have been more inclined to add new case studies than to remove old ones, but in the interest of keeping the length reasonable we have often opted for new images with long legends that constitute mini case studies. In short, this edition represents a substantial "overhaul" from the last edition.

Royalties from this book continue to support conservation students from developing countries and have finally reached a level sufficient to fund an endowed scholarship. Indeed, the first recipient, a student from Brazil, begins her PhD work 2 weeks from today.

A quarter of a century has passed since I finished the preface to the first edition of this book, and in many respects the world and this book are profoundly different. However, much remains the same: life on Earth is awesome, in the original, fundamental sense of that word, and now, more than ever, it needs the attention of dedicated stewards like you.

M. L. Hunter, Jr.

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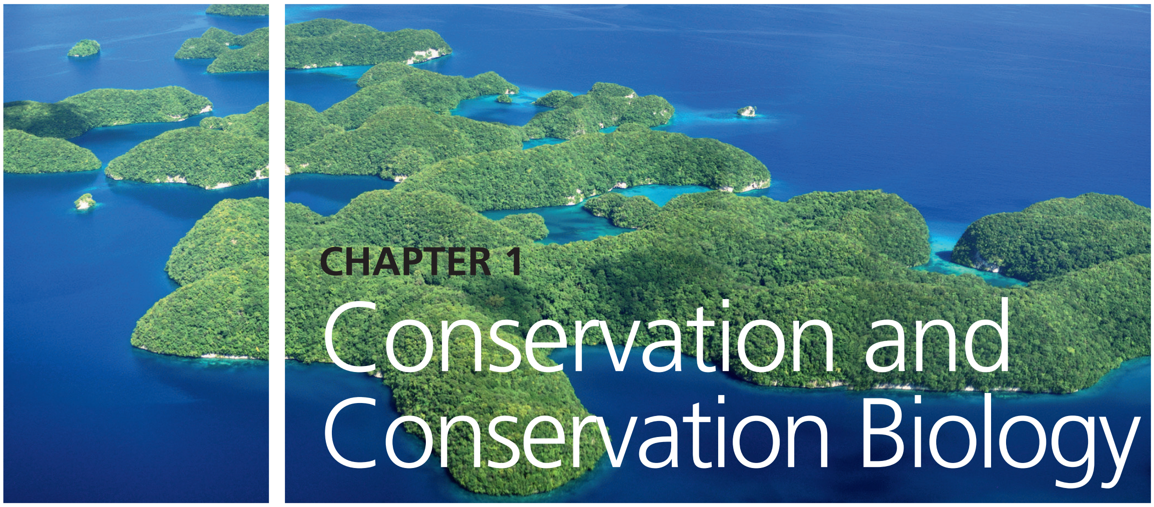
PART I

Biodiversity and Its Importance

Think about our world and its wild things: a marsh splashed and flecked with the colors of flowers and dragonflies, the rhythmic roar and swoosh of waves punctuated by the strident calls of gulls, a dark forest pungent with the odors of unseen life teeming below a carpet of leaves and mosses. Now imagine a future world utterly dominated by concrete and regimented rows of crops – a hot, dry, monotonous, and unhealthy home for us and the species we have chosen for domestication. This book is about hope in the face of forces that would degrade our world. This book is about the rich tapestry of life that shares our world now and about how we can maintain it, sometimes in places that we protect and set aside, more often in places where we share the lands and waters with a wide range of other species.

The abundance and diversity of life is often apparent where water meets land, especially intertidal zones. In this photo representatives of four different phyla are evident and there are likely to be dozens of species unseen. (Terry Allen/Flickr)



CHAPTER 1

Conservation and Conservation Biology

What Is Conservation?

Since the beginning of humanity people have been concerned about their environment and especially its ability to provide them with food, water, and other resources. As our numbers have grown and our technology has developed, so has the impact we are having on our environment, and thus we are becoming increasingly concerned. Media everywhere proclaim the current issues:

- "Conservationists call for tighter fishing regulations."
- "Ecologists describe consequences of warmer climates."
- "Environmentalists criticized by chemical industry."
- "Preservationists seek more wilderness."

These headlines also reveal an ambiguous terminology. Are we talking about conservation or preservation? Are the issues ecological or environmental? Students deciding which university to attend and which major to select are faced with a bewildering array of choices – soil and water conservation, environmental studies, natural resource management, conservation biology, wildlife ecology, human ecology, and more – that intertwine with one another. In this chapter we will try to resolve these ambiguities by examining how they are rooted in human history and ethics. To start on common ground we explore the key differences and similarities among conservationists, preservationists, environmentalists, and ecologists. In the second part of the chapter we will see where conservation biology fits into this picture.

A *conservationist* is someone who advocates or practices the sustainable and careful use of natural resources. Foresters who prudently manage forests, hunters and fishers who harvest wild animal populations sustainably, and farmers who practice the wise use of soil and water are all conservationists.

Fundamentals of Conservation Biology, Fourth Edition. Malcolm L. Hunter, Jr., James P. Gibbs and Viorel D. Popescu.

Companion website: www.wiley.com/Conservation-Biology4e

Citizens who are concerned about the use of natural resources are also conservationists and sometimes they assert that the activities of foresters, fishers, farmers, and other natural resource users are not prudent, sustainable, or wise. In theory, arguments over who is, or is not, a conservationist should turn on the issue of what is sustainable. In practice, most foresters, farmers, ranchers, and others – many of whom are careful stewards of the lands and waters they control – have ceded the title "conservationist" to their critics.

A *preservationist* advocates allowing some places and some creatures to exist without significant human interference. Most people accept the idea that conservation encompasses setting aside certain areas as parks and protecting certain species without harvesting them. The divisive issues are: how many and which areas, and which species. Many resource users believe that enough areas have already been closed to economic use, and they use "preservationist" as a negative term for people they consider to be extremists. Ironically, in the case of some set asides, like marine reserves, their preservation boosts fish harvests in surrounding areas. Nevertheless, because of this pejorative use, relatively few people call themselves preservationists. People who find themselves labeled preservationists by others usually prefer to think of preservation as just one plank in their platform as conservationists.

An *environmentalist* is someone who is concerned about the impact of people on environmental quality in general. Air and water pollution are often the proximate concerns; human overpopulation and wasteful use of resources are the ultimate issues. There is enormous overlap between environmentalists and conservationists. Many environmentalists would say that environmentalism encompasses conservation, while many conservationists would say the reverse. The difference is a matter of emphasis. By focusing on air and water pollution and their root causes, environmentalists often emphasize urban, suburban, and agricultural situations where human-induced problems and human well-being are paramount. Because conservationists focus on natural resource use, they tend to emphasize the rural areas and wildlands where natural resources are most abundant, as well as associated ecosystems and organisms, including people who might live there.

Traditionally, an *ecologist* is a scientist who studies the relationships between organisms and their environments. However, in the 1970s when concern for the environment first bloomed widely around the planet, the term developed a second meaning when the public failed to distinguish between environmentalists (activists) and the scientists (ecologists) who provided the scientific basis for the environmental movement. Now "ecologist" is often used in the popular press as a synonym for "environmentalist." Given this, a broader definition of an ecologist is a person who is concerned about the relationships between organisms (including people) and their environments.

Recently, these distinctions have become controversial and fuzzy, following a call for a "new conservation" that focuses on the benefits that nature provides for people (Kareiva and Marvier 2012) and the ways that people and nature depend on one another. This "conservation for people" movement is controversial because other people believe that conservation should also recognize the intrinsic value of nature (see next section). It is fuzzy because people on both sides of the argument have lost sight of the fact that the origins of conservation (also see next section) were largely centered on human welfare (Hunter et al. 2014).

In summary, ever-evolving attitudes and perceptions are at the root of the confusion over who are conservationists, preservationists, environmentalists, and ecologists; each term persists because it has some utility in describing the diverse ways people interact with their environment.

A Brief History of Conservation

The roots of conservation are lost in prehistory (Fig. 1.1). No doubt there was a time when human reason, growing ever more sophisticated through the millennia, began to extend the idea of deferred gratification ("save this fruit to eat tomorrow rather than now") over much longer periods. Keep in mind that for 99% of our history as a species we were living in small, self-regulating groups of humans entirely dependent on wild species. Thus conservation has long been intrinsic to our welfare as expressed in the form of edicts and practices such as "Leave these tubers so there will be more next year when we pass this place." Or "Do not kill the pregnant females in this herd of peccaries so next year we will have even more to eat." Or "Nobody shall hunt in that sacred area near our home grounds." Certainly, such practices were simple, almost analogous to the food caching exhibited by many animals, but they were widespread and effective in governing human activity and represent conservation nevertheless. They remain relevant to this day, most notably in

Figure 1.1 The roots of conservation can probably be found among the earliest *Homo sapiens* such as the people who painted this mural in the Lascaux cave in France. (Thipjang/Shutterstock)

the practices of indigenous people who still live subsistence lifestyles in self-regulating societies using wild species (Berkes and Turner 2006).

Leaping forward, history records many examples of conservation throughout the ages and across cultures. For example, the biblical story of Noah's ark remains a popular metaphor for conservation, and the Bible also codifies the first-known game conservation law:

> If you come on a bird's nest, in any tree or on the ground, with fledglings or eggs, with the mother sitting on the fledglings or on the eggs, you shall not take the mother with the young. Let the mother go, taking only the young for yourself, in order that it may go well with you and you may live long. (Deuteronomy 22:6–7)

(In other words: don't kill mother birds.)

A far broader law was promulgated by Asoka, emperor of India 274–232 BCE:

> Twenty-six years after my coronation I declared that the following animals were not to be killed: parrots, mynahs, … wild geese, … cranes, bats, queen ants, terrapins, … tortoises, and porcupines, squirrels, twelve-antler deer, … rhinoceroses, … and quadrupeds which are not useful or edible.… Forests must not be burned.

Many laws focused on regulating rather than prohibiting the exploitation of species. For example, Middle Eastern pharaohs issued waterfowl hunting licenses, and night hunting was banned in the city-states of ancient Greece (Alison 1981). Early regulations emphasized trees and birds, mammals, and fish caught for food, but all species and whole ecosystems benefitted from the popularity of declaring preserves. Starting at least 3000 years ago with Ikhnaton, king of Egypt, and continuing with the royalty of Assyria, China, India, and Europe, as well as with the Greeks, Romans, Mongols, Aztecs, and Incas, history has recorded many decrees setting aside land to protect its flora and fauna (Alison 1981).

Conservation was an issue during the period when European states were colonizing the rest of the world because colonization often led to disruption of traditional systems of natural resource use and rapid overexploitation. Freedom from European game laws was a significant stimulus to colonization, and hunting was a major preoccupation of the colonizing class. Imagine how attractive the promise of abundant, freely available game would seem to people who feared for their lives whenever their appetite for meat led them to poach one of the king's deer. This phenomenon was particularly true on some small, tropical islands such as Mauritius and Tobago, and continental Africa (Grove 1992, 1995; Prendergast and Adams 2003).

Of course game species did not fare well under the onslaught of hungry colonists and soon regulations had to be enacted. For example, as early as 1639 it was illegal to kill deer between May 1 and November 1 in parts of Rhode Island (Trefethen 1964) and the Cape Colony in southern Africa had game laws by 1822 (MacKenzie 1988). This basic pattern – human populations growing, developing new technology for using natural resources, leaving crowded places and colonizing new lands, disrupting and displacing native peoples and their long-standing practices in these colonized areas, and then responding to overexploitation and expanding population with an array of ever more restrictive regulations – has been repeated across the globe and continues to this day.

With increasing human impacts, the abuse of resources other than trees and large animals also began to be recognized, albeit slowly, for species that lack obvious economic value such as most invertebrates, small plants, amphibians, and reptiles. Aldo Leopold (1949) called for saving every species with his well-known admonition, "To keep every cog and wheel is the first precaution of intelligent tinkering," but it was not until the 1960s and 1970s that the idea of "endangered species" (so imperiled that they were about to disappear from the face of the Earth forever) became a major issue for conservationists. During this period many nations passed laws (e.g. the United States Endangered Species Act) to form an umbrella under which all animal and plant species threatened with extinction could, in theory, benefit from conservation intervention. In practice, however, plants and smaller animals still are not given equal treatment, and other components of biodiversity such as microorganisms, genes, and ecosystems are usually not explicitly under the umbrella at all.

This brings us to the point of departure for conservation biology and this book, but first let us briefly return to preservation, environmentalism, and ecology to see how they mesh with the larger history of conservation.

Preservation

The roots of preservation are probably almost as ancient as the origins of spirituality. When religious leaders began to set rules for society, some species were protected as totems and some places like certain mountains were recognized as sacred and thus decreed off-limits or visited only on religious occasions (Fig. 1.2). Moving ahead many millennia, the establishment in 1872 of Yellowstone National Park, the world's first national park, is often identified as the beginning of governmental policy codifying the value of preservation. Here were nearly 10,000 square kilometers of evidence that society valued the landscape's sacredness; that its aesthetic qualities (particularly striking geological features like geysers and hot springs) justified removing some natural resources from the path of economic development. The national park movement has developed throughout the world and has been modified in many ways. Some preserves are off-limits even to visitors, such as the many zapovedniks (strictly protected areas) of Russia, while some parks, especially in Europe and India, maintain traditional cultural practices such as historic livestock grazing regimes. Nevertheless, the underlying value system remains largely intact. This same preservationist value system has also curtailed the exploitation of some species, such as various kinds of

Figure 1.2 Mount Fuji [*top*] has been a sacred mountain for the Buddhists and Shintoists of Japan for many centuries. (Tofoli.douglas/Flickr/Public domain) For the indigenous people of the Pacific Northwest, totem poles [*bottom*] often depict species that represent family identity and history, and have a sacred role in their culture. (Bernard Spragg/Flickr/CC0)

whales and songbirds, in many places. Obviously, species that are on the brink of extinction are slated for preservation, but others are simply species for which preservation has been deemed preferable to utilization. Many countries, for example, have banned the harvesting of all songbirds even though some species could be harvested in a sustainable manner.

Environmentalism

The first environmentalists were probably citizens of our earliest cities, more than 2000 years ago, who demanded sewers and chimneys to mitigate the impact of water and air pollution, respectively. For example, the Cloaca Maxima (which literally means "greatest sewer") was built in Rome around 600 BCE. The industrial revolution accelerated urbanization and brought its own problems such as coal burning and factory discharges into water bodies. Environmental issues became much more high profile after publication of Rachel Carson's 1962 treatise on pesticides, *Silent Spring*, and a global environmental movement finally coalesced at the first United Nations Conference on the Human Environment, in Stockholm in 1972. This event marked the beginning of an era of considerable effort toward environmental protection at the global, national, and local levels with many organizations created, laws passed, and treaties ratified.

Ecology

The elements of modern ecology can be traced to Hippocrates, Aristotle, and other Greek philosophers, but it was probably Alexander von Humboldt (1769–1859) who first articulated truly sophisticated ecological ideas, for example linking air pollution and deforestation to climate change (Wulf 2015). Nevertheless, the word "ecology" was not coined until 1869. Scientific societies of ecology and ecology journals followed in the early 1900s, and ecology soon proved useful in developing a scientific basis for forestry and other areas of natural resource management. However, ecology did not move into the public eye until the advent of environmentalism. As the environmental movement spawned new government agencies, advocacy groups, and consulting firms, universities educated large numbers of young ecologists to fill these organizations. Schools at all levels began informing students about the relationships between organisms and their environment. Consequently, there are now many professional ecologists and other experts who focus on the science of solving environmental problems, and many more people who are activists and call themselves ecologists out of concern for these issues.

An Overview of Conservation Ethics

It is easy to describe the history of conservation in terms of political benchmarks such as the passage of laws, but these are only a manifestation of a more fundamental process: the evolution of human value systems or ethics with respect to the environment. We will encounter conservation ethics in many chapters and will focus on the topic in Chapter 15, "Social Factors," but a brief preview here will complement our history of conservation and will provide a foundation for later chapters. To do so, we place conservation ethics into an historical context using three people – John Muir, Gifford Pinchot, and Aldo Leopold – as the vehicles to describe three fundamental ethics that underpin conservation today: the Romantic-Transcendental Preservation Ethic, the Resource Conservation Ethic, and the Evolutionary-Ecological Land Ethic, respectively (Fig. 1.3) (Callicott 1990).

The *Romantic-Transcendental Preservation Ethic* became the basis for political action, most notably in the hands of John Muir (1838–1914), the writer and naturalist who founded the Sierra Club. Muir believed that communion with nature brings people closer to God (thereby providing a "transcendent" experience) and that visiting ancient forests and alpine meadows for this purpose is morally superior to using them to cut timber or graze livestock. In other words, nature is a temple that is sullied when people exploit it. Obviously, such an ethic puts a high premium on establishing parks to preserve nature.

At about the same time that Muir was calling for extensive preservation, Gifford Pinchot (1865–1946) was formulating a very different value system, the *Resource Conservation Ethic*. Pinchot was a forester and politician and founder of the US Forest Service. To Pinchot, nature consisted solely of natural resources that should be used to provide the greatest good for the greatest number of people for the longest time. This was not a call to plunder the land but rather to use it in a way that distributes benefits fairly and efficiently among many people, rather than among a few lumber barons and cattle kings, as was largely the case in his day. It also advocated wise, judicious use of natural resources so that future generations would not be shortchanged. By recognizing aesthetics as a resource, the Resource Conservation Ethic even found room for a modest amount of preservation to accommodate

Figure 1.3 Put yourself in the shoes of John Muir, Gifford Pinchot, and Aldo Leopold to view this landscape. How does this influence your perspective? (James P. Gibbs, author)

Transcendental philosophers and Romantic poets. Given these precepts and a history of overexploitation, Pinchot believed that natural resources should be owned or regulated by government.

Although there was a profound gap between Muir's and Pinchot's ethics, they both espoused an anthropocentric (people-centered) view of nature. They both wrote of nature's utility — its *instrumental value* in the terminology of philosophers. One promoted nature as a source of spiritual enlightenment, the other as a source of commodities, but neither claimed that nature had *intrinsic value,* value independent of its usefulness.

With the emergence of the science of ecology and the writings of Aldo Leopold (1886–1948) – known as the founder of wildlife conservation as a professional discipline and, ironically, a man who began his career eradicating predators but ended it as a strong advocate of wilderness – one finds a utilitarian perspective of species being questioned:

> Ecology is a new fusion point for all the sciences. The emergence of ecology has placed the economic biologist in a peculiar dilemma: with one hand he points out the accumulated findings of his search for utility or lack of utility in this or that species; with the other he lifts the veil from a biota so complex, so conditioned by interwoven cooperations and competitions, that no man can say where utility begins or ends. (Leopold 1939)

Leopold was explaining that because nature is an integrated system with transcendent properties and functions beyond a mere collection of the species that comprise it, each species is important as a component of the whole and thus has instrumental value because of its role in an ecosystem. This was the key idea that spawned the *Evolutionary-Ecological Land Ethic*. It took Leopold's ethical vision beyond the choice of either preserving nature as inviolate or efficiently developing it. Muir wrote of the equality of species in religious terms; Leopold expressed equality in ecological terms. Pinchot (1947) stressed the dichotomy between people and nature ("there are just two things on this material earth – people and natural resources"); Leopold thought of people as citizen-members of the biotic system. Leopold's ideas gave people the right to use and manage nature *and* the responsibility of doing so in a manner that recognized the intrinsic value of other species and whole ecosystems. Indeed, he contended that the very tools that had been so frequently used to destroy the environment (namely the axe and the plow) could also be creatively applied to heal it, especially if guided by science.

All three of these ethics are still prevalent. The Resource Conservation Ethic resonates with the natural resource–based industries and the associated government agencies that regulate them (although some would argue a profit motive is more dominant than a conservation ethic). Some environmental organizations are wedded to the Romantic-Transcendental Preservation Ethic, reflecting a membership that uses nature primarily for spiritual rejuvenation. Consider the Wilderness Society, for example, and its frequent allusions to the spiritual reasons for "saving" nature. The Evolutionary-Ecological Land Ethic characterizes various groups that try to find a practical balance between the needs of people and nature, such as the World Wide Fund for Nature or The Nature Conservancy.

In the conclusion to his essay, Callicott (1990) asks some provocative questions. If people are valid members of the biotic community as Leopold asserts, why do we turn to landscapes without people (at least without industrial era people) to set benchmarks for what is natural? If beavers and reef-building corals can shape landscapes in positive ways, why can't people? Can people improve natural ecosystems? Can they promote and generate biological diversity? These are not simple issues, and we will return to them frequently in this book because this dynamic, often difficult, interface between people and nature is the crux of conservation and conservation biology.

What Is Conservation Biology?

So where does conservation biology fit among these larger issues? Conservation biology is the applied science of maintaining the Earth's biological diversity. A simpler, more obvious definition – biology as applied to conservation issues – would be misleading because conservation biology is both less and more than this. It is narrower than this definition because there are many biological aspects of conservation, such as biological research on how to grow timber faster, improve water quality, or graze more livestock, that are only tangentially related to conservation biology. On the other hand, it reaches far beyond biology into disciplines such as philosophy, economics, and sociology that are concerned with the social environment in which we practice conservation, the reasons we are motivated to maintain biodiversity, and disciplines such as law and education that shape the ways we implement conservation (Jacobson 1990; Soulé 1985). Fifty years ago, maintaining biological diversity simply meant saving endangered species from extinction and was considered a small component of conservation, completely overshadowed by forestry, soil and water conservation, fish and game management, and related disciplines. Now we know that we need a healthy and diverse biota for our own well-being. And with so many species at risk of extinction and the idea of biological diversity extending to genes, ecosystems, and other biological entities, conservation biology has moved into the spotlight as the crisis discipline focused on saving life on Earth, perhaps the major issue of our time (Wilson 1992).

Conservation biology is best conceptualized as an amalgamation of disciplines as depicted in Fig. 1.4 (Jacobson 1990). It sits between basic

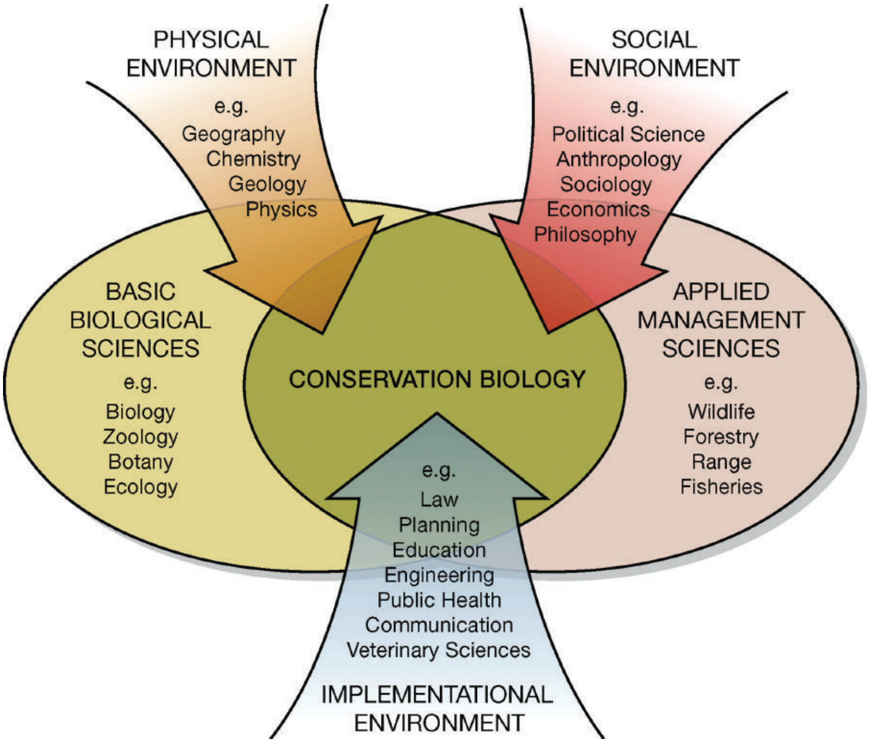


Figure 1.4 A schematic view of the relationship between conservation biology and other disciplines. (Jacobson 1990/ John Wiley & Sons)

biological sciences and natural resource sciences because it originated largely with biologists who have created a new natural resource science. It is different from traditional natural resource sciences because it places relatively greater emphasis on all forms of life and their intrinsic value, compared with traditional other natural resource sciences that usually focus on a few economically valuable species (Soulé 1985). Like natural resource sciences, conservation biology is influenced by the earth sciences because it addresses issues with strong environmental linkages. Finally, conservation biology depends heavily on social sciences, law, education, and other disciplines because it operates in the world of human socio-economic–political institutions and seeks to change those institutions to allow people to coexist with the rest of the world's species.

This model also illustrates how any student wishing to become a conservation biologist needs to focus on courses in the basic biological sciences and the applied sciences of natural resource management while acquiring a substantial understanding of the subjects that shape the legal, policy, social and cultural arena within which conservation operates. This has also led to a growing role and critical role for students with a primary background in law, economics, communication, education and so on, and a secondary foundation in biology. In fact, the term "conservation science" is increasingly favored rather than "conservation biology" because the field is about so much more than biology.

A Brief History of Conservation Biology

The deepest, longest roots of conservation biology are widespread but its emergence as a discipline is usually attributed to the First International Conference on Conservation Biology held in San Diego, California, in 1978, and to the book that followed, *Conservation Biology* (Soulé and Wilcox 1980). Eight years after this small beginning the Society for Conservation Biology was formed, and it launched a new journal, *Conservation Biology*, in 1987 (Fig. 1.5). The society and its journal flourished, and universities, foundations, private conservation groups, and government agencies nurtured this growth with an array of conservation biology programs (Jacobson 1990; Meine et al. 2006).

The founders of conservation biology had many more links to institutions of basic biological sciences (e.g. genetics, zoology, botany) than to natural resource management institutions and they wove some novel and diverse intellectual threads into the discipline's tapestry. Ideas from evolutionary biology, population dynamics, landscape ecology, and biogeography provided a new understanding of the diversity of life, its origins and maintenance, how it is distributed around the globe, and what threatens it.

By forming a new professional society dedicated to the maintenance of biological diversity, conservation biologists partly overlapped the domain of some older professional societies. This was especially true of The Wildlife Society, which, on the very first page of *The Journal of Wildlife Management*, described wildlife management as "part of the greater movement for conservation of our entire native flora and fauna" (Bennitt et al. 1937). Today wildlife managers place an ever-growing emphasis on endangered and nongame species, including reptiles, amphibians, and sometimes even invertebrates and plants. However, much of their attention, arguably most, is still focused on "game" species, in large part because most of the funding for wildlife management agencies comes from the fees hunters and anglers are required to pay. Perhaps, if more wildlife managers had reached out to embrace all forms of life that are wild, not just the vertebrates, and to work with a constituency of all people who care about nature, not just hunters and anglers, then conservation biology might never have arisen as a separate discipline. This is especially apparent if one defines "wildlife" as "all forms of life that are wild," a definition that overlaps substantially with biodiversity. Notably, the first institution to apply science to conservation was the "Roosevelt Wild Life Station," established in 1919 to integrate science, natural history, and natural resources management for training a new generation of students to

Figure 1.5 The Society for Conservation Biology began publishing *Conservation Biology* in May 1987 and held its first conference that June.

implement this new idea of "conservation" of "wild life." To be clear that this book uses a broad definition, we retain the original, two-word spelling, "wild life." As you can see, these terms "wildlife," "wild life," "biological diversity," and "biodiversity" have a long and inter-related history and still remain in use in different contexts.

CASE STUDY 1.1

Return of the Tortoises to Española Island[1]

The year is 1960. On the island of Española, a low dry expanse of eroding lava far to the southeast in the Galápagos Archipelago, a giant tortoise rests under a bush and gazes out to sea. The edges of her shell flare out dramatically – a distinctive characteristic of her lineage – but lichens cover it, a sign that she has not met with and bred with another tortoise in decades. Moreover, her head lies weakly on her outstretched forelimbs, her body withering within her shell. Beyond the small bush sheltering her from the blazing sun, hooves of goats thud against rock and dust swirls. Kids bleat hungrily after their mothers. The island is devastated, and even the goats are starving, driven to eat seaweed and drink seawater. The magnificent stands of arboreal cactus that once crowned the island are gone, torn down and stripped of their pads. Gone also is the carpet of fragile herbs and grasses that once covered the island, species that the large tortoises with their soft elephant-like feet and simple "beak" could only graze, but the toothed and hooved goats could destroy. Even the finches and mockingbirds that flitted about noisily in search of seeds and insects on the leaves of shrubs have mostly disappeared. Little remains but patches of prickly mesquite and expanses of exposed, powdery earth, from which lava blocks protrude polished brightly by the shells and claws of thousands of generations of giant tortoises. But they too are now all gone. Seemingly only the old female tortoise remains.

By the 1950s the Española Island tortoise had been given up as extinct. The island was low and accessible and the first stop for many whaling ships visiting the Galápagos in the 1800s. These sailing ships disgorged hungry sailors, who wobbled on their unstable "sea legs" deep into the trackless island, smoking clay pipes and clutching precious water supplies in fragile, hand-blown glass bottles. After much searching these sailors would haul tortoises down to the shore, likely thousands of them. Back on their ships the sailors stored the tortoises below decks where they survived for up to a year, without food or water, waiting to be slaughtered one by one to provide occasional fresh meat for the often scurvy-ridden crew. After decades of such depredations even the whaling ships stopped visiting Española once word got around that there were "no more" tortoises. Introduction of goats to the island (presumably to supply another source of meat for future visits) made matters even worse. By the 1950s boats passing the island reported the enormous goat population and wasted landscape, apparently confirming the demise of the Española Island tortoise.

One person, however, held out hope. In 1959 Miguel Castro was appointed as the first tortoise warden for the newly formed Galápagos National Park, which brought the first protections to these largely abandoned islands. He had a tough task ahead of him: starting the first program to protect these magnificent reptiles, which had been subject to plunder for two centuries and remained mere sources of bush meat for most local people, themselves scratching a living out of this austere landscape. Castro sailed a small boat to Española and made a brief reconnaissance trip in August 1963. Perhaps some tortoises might still exist. After much wandering around he found a single tortoise eating a torn-down cactus in the company of 15 goats. If there was one, perhaps there might be more? His curiosity piqued, Castro made a second trip in November 1963. Again he saw mostly goats, thousands of them, busily stripping bark from cactus tree roots, causing the cacti to fall over. Remarkably he also found the same tortoise he had found in August. He then found another tortoise, in a different part of the island, living in isolation. The signs were positive that perhaps a small nucleus of tortoises might survive.

Further trips to Española located more individuals. Some 14 were eventually relocated and brought into captivity near Park headquarters on another island. Once together in captivity, mating quickly ensued among the tortoises, who were now enjoying abundant food compared to life on their goat-devastated island, perhaps the first breeding to occur in a half century!

But producing young tortoises was not easy. Nobody had successfully bred giant tortoises in large numbers before. Even the best zoos of Europe and the United States had tried and failed. Conventional wisdom was that it was not possible. Through trial and error, another park guard, Fausto Llerana, along with many helpers and advisors, gradually developed tortoise husbandry.

One lingering problem was that the small nucleus of remaining adults had a very skewed sex ratio: 12 females and just two males. So the international search for more Española tortoises began. Old records were unclear but suggested that a group of tortoises had been removed from Española and shipped to San Diego, California, around 1935. Perhaps some yet survived 35 years later in distant California? Further investigation revealed that there was indeed a male still alive from that shipment. So-called "Diego" was large and still extremely vigorous. He was boxed up and after several false starts trying to find an aircraft suitable to transport him, he was finally flown to Ecuador and then sailed back to Galápagos in August, 1977. The captive population became strikingly more productive shortly after Diego's arrival. Diego is to this day a prolific breeder.

The captive Española tortoises also had a major, unanticipated and ancillary benefit – educational and public relations value. Local people, especially school children, and tourists visited (and still do) the rearing center with its breeding enclosures and incubators. Visitors can still see the hatchlings clustered around their water baths. The breeding program came to serve as a prime example of what could be done to reclaim some of what had been lost in Galápagos. It remains a major attraction to visitors.

Once numbers in captivity had built up and the Española tortoises were out of danger of outright extinction, the Galápagos National Park Service turned its attentions to remedying the problems on the tortoises' home turf back on Española. During the 1970s, about 3000 goats were eliminated from Española through an intense hunting campaign by park guards. Groups of guards with rifles, stout boots, and jugs of water would go to the field for weeks and even months and hunt down the goats. The terrain was difficult and the comforts few. They lived largely off what they hunted. Huge numbers of goats were culled early in the process but the very last goats took many months to eliminate. The last goats were of course the wiliest ones of all; the hunters knew each by their coat colors. The guards eventually succeeded, through sheer dedication and skill. Now just a few skulls of goats and dessicated goat droppings can be found on the island, weathering to bright white in the blazing sun

After the goats were removed the repatriations of the first hatchling tortoises began in 1975. Areas of the island with the last remaining patches of cactus were chosen as special release sites because the cactus provides critical food, moisture, and shade for young tortoises. Boxes of 5-year-old hatchlings were transported first by sea and then up the rocky slopes of the islands in backpacks and released one by one.

The captive population generated over 2000 offspring repatriated to Española. Of the repatriated tortoises, perhaps half died of natural causes but half survived and grew well (Gibbs et al. 2014). Most significantly, after nearly 30 years of reintroductions, some of the first repatriates have grown to adulthood. These repatriated tortoises are now reproducing on Española (Fig. 1.6). Nests can be found and occasionally, a soft-shelled, tiny tortoise newly emerged from its nest.

The population is again secure and sustaining itself. But not all is well. The vegetation has recuperated rapidly now that the goats are gone, but perhaps too rapidly as it has become impenetrable in many areas, even blocking movements by the newly arrived tortoises. The slow-growing cacti remain scattered and rare but they are showing signs of recovery, now that the tortoises are back to disperse their seeds.

Coda

The Española tortoises, once abandoned and quietly relegated to extinction, have returned to their native ground. All 15 surviving tortoises found 60 years ago are still alive in June 2020 and all were retired back to their original home on Española to be with their hundreds of offspring and "grand-offspring." They are now essentially taking care of themselves. Humans can step back out of the picture, after being a destructive force and then a healing one, and let the tortoises and their ecosystem resume interacting as they did for thousands of years previously. Conservation has succeeded. It was accomplished by a cadre of dedicated individuals, mostly Ecuadorian park managers and scientists with some foreign support, working with scarce funds. Because of the program's success, Española tortoises are now being liberated on another island – nearby Santa Fe Island that lost its tortoises 200 years ago – to restore the ecological role of tortoises there and develop an "insurance" colony for Española tortoises. It is an example of the awesome power of humans to control the fate of wild life. It is also an example of how we can be both agents of destruction and benevolent stewards of restoration. This book seeks to explore these issues with you in much greater detail and to provide guidance on achieving positive outcomes for the many creatures around the world that, like the Española tortoises, are still struggling to survive.

Figure 1.6 This Española tortoise was among the very first repatriated to the island as a small hatchling some 25–30 years ago once goats had been removed and the island's habitat restored. It is likely one of the tortoises now responsible for the new hatchlings appearing again on the island, representing the first reproduction in this population in many decades. At right is Mr Fausto Llerena, a park guard and tortoise keeper of over 40 years, who largely is responsible for figuring out how to breed Galapagos tortoises in large numbers in captivity. (James P. Gibbs, author)

1 Primary sources for this section were: Marquez et al. (1991), Milinkovitch et al. (2004), Gibbs et al. (2014), and personal observations.

Summary

People who care about nature and the natural resources we obtain from nature, such as clean air and clean water, come with many labels: conservationists and preservationists, environmentalists and ecologists. Although these people share many goals, their priorities can differ. For example, conservationists advocate the careful use of natural resources, whereas environmentalists often emphasize maintaining an uncontaminated environment. The history of conservation has a recurring theme: people being forced to limit their use of natural resources more and more as human populations grow and technological sophistication increases. Conservation history is marked by practices and laws regulating our use of natural resources, but more fundamental is the evolution of our ethical attitudes toward nature and its intrinsic and instrumental values. Three ethical positions underpin our motivation and practices to conserve biodiversity: (1) the Romantic-Transcendental Preservation Ethic (briefly, nature is best used for spiritual purposes); (2) the Resource Conservation Ethic (nature is natural resources to be carefully developed for human purposes); and (3) the Evolutionary-Ecological Land Ethic (people are part of nature and have both the right to change it and a responsibility for respecting the intrinsic value of other species and ecosystems in general). Conservation biology is the applied science of maintaining the Earth's biological diversity. It differs from basic biologic sciences because it reaches out to economics, law, education, politics, philosophy, and other subjects that shape the human world within which conservation must operate. It differs from traditional natural resource sciences because it places relatively greater emphasis on all forms of life and their intrinsic value, compared with other natural resource sciences, which typically focus on relatively few species with high instrumental (usually economic) value.

FURTHER READING

A comprehensive world history of conservation would be voluminous but some succinct overviews are available (Hughes 2009; Simmons 2008). If you want more depth there are whole encyclopedias (Krech et al. 2004), even one covering just the United States (Brosnan 2011). Many books cover certain times, phenomena, and places; for example, the sixteenth to eighteenth centuries (Richards 2003), the twentieth century (McNeill 2000), European colonization (Grove 1995), collapse of civilizations (Diamond 2005), Canada (MacDowell 2012), Latin America (Miller 2007), the Mediterranean (Hughes 2005), and the United States (Merchant 2007). Also see the journal *Environmental History*. Articles by Soulé (1985), Callicott (1990), and Jacobson (1990) form a foundation for the latter parts of the chapter and merit further reading. For relevant websites, check out the Society for Conservation Biology's website at conbio.org and some of the major international conservation groups at www.iucn.org, wwf.org, www.nature.org, www.conservation.org, and www.worldwildlife.org.

TOPICS FOR DISCUSSION

1. Do you think of yourself primarily as a conservationist, environmentalist, ecologist, or preservationist, or none of these? Why?
2. Which of the three ethics discussed do you think will be predominant 50 years from now? Why? Would you feel comfortable promoting one of these ethics among your friends and family?
3. Name some organizations that exemplify each of the three ethics today. Have any of these organizations changed their philosophy?
4. Can you identify examples of how each of the disciplines in Fig. 1.4 has contributed to conservation of a specific species in danger of extinction?

CHAPTER 2
What Is Biodiversity?

A tropical forest ringing with a cacophony of unseen frogs, insects, and birds; a coral reef swirling with schools of myriad iridescent fishes; a vast tawny carpet of grass punctuated by herds of wildebeest and other antelope – these images are well known, and for many people they all revolve around a central issue and a single word: “biodiversity” (Fig. 2.1). Some have argued that “biodiversity” is too vague and trendy a word to be useful, but it does succinctly imply a fundamental idea: life on earth is extraordinarily diverse and complex. This idea is not as well captured in other words such as “nature” or “wild life.” Furthermore, “biodiversity” entered the public vocabulary at a time when the global scope of threats to life on Earth became apparent; thus, to many people, the term carries a conviction to stem the loss of the planet’s life-forms.

Definitions of biodiversity usually go one step beyond the obvious – the diversity of life – and define biodiversity as the variety of life in all its forms and at all levels of organization. “In all its forms” reminds us that biodiversity includes plants, invertebrate animals, fungi, bacteria, and other microorganisms, as well as the vertebrate animals that garner most of the attention. “All levels of organization” indicates that biodiversity refers to the diversity of genes and ecosystems, as well as species diversity. The idea that biodiversity has levels of organization introduces a complexity that we will explore in the next three chapters, “Species Diversity,” “Ecosystem Diversity,” and “Genetic Diversity,” after a brief overview here. (For a novel approach to understanding biological complexity, see Kim et al. [2019] and their analysis of biochemical networks that reach from individual organisms to the whole biosphere.)

Fundamentals of Conservation Biology, Fourth Edition. Malcolm L. Hunter, Jr., James P. Gibbs and Viorel D. Popescu.

Companion website: www.wiley.com/Conservation-Biology4e

Figure 2.1 There are few places where biodiversity is as conspicuous as a coral reef. (Hans Chehaiber/Flickr/CC BY 1.0)

Species, Genes, and Ecosystems

It is easiest to comprehend the idea of maintaining biodiversity in terms of species that are threatened with extinction. We know about blue whales, giant pandas, and whooping cranes, and we would experience a sense of loss if they were to disappear, even though most of us have never encountered them except as digital representations in an electronic medium. For most mosses, lichens, fungi, insects, and other obscure species it is much harder to elicit concern. Nevertheless, many people are prepared to extend some of the feelings they have for whales, pandas, and cranes to species they do not know, as an expression of their belief that all species have some intrinsic value.

Genes can also be hard to understand and appreciate. These self-replicating pieces of DNA that shape the form and function of each individual organism are the organism's fundamental blueprint, but also important are water, oxygen, and thousands of other molecules. It is not the genes themselves that conservation biologists value; it is the diversity that they impart to organisms that is so essential. If two individual strawberry plants have a different set of genes, one of them might be better adapted to fluctuations in water availability and thus would be more likely to survive a period of climate change. One of them might be less susceptible to damage from ozone and other types of air pollution. The fruit of one might be more resistant to rotting and therefore its progeny might prove useful to strawberry breeders and farmers. Perhaps the fruits simply taste or look different and thereby provide aesthetic diversity. It is these expressions of genetic diversity that we value. The diversity of life is rooted in genetic differences among individuals and the processes of evolution that amplified and shaped these differences among populations to generate distinct species and ultimately the higher taxonomic levels: genera, families, orders, and so on.

Unlike genes, ecosystems are large and conspicuous, and thus anyone with the most rudimentary understanding of ecology appreciates the value of a lake, a forest, a wetland, and so on. Nevertheless, ecosystems can be hard to define in practice. Where do you draw the boundary between a lake and the marsh that surrounds it when many organisms are moving back and forth between the two? This sort of problem can complicate the role of ecosystems in biodiversity conservation. Conservation biologists often advocate protecting examples of all the different types of ecosystems in a region, but how finely should differences be recognized? Is an oak–pine forest ecosystem that is 60% oak and 40% pine appreciably different from one that is 40% oak and 60% pine? If you look hard enough, every ecosystem will be unique. The rationale for protecting ecosystem diversity also differs. Some conservationists advocate protecting ecosystems for their intrinsic value as independent, biological entities of many interacting species, whereas others think of protecting ecosystems simply as an efficient way to protect most of the species that form the ecosystem.

Structure and Function

The definition of biodiversity provided above emphasizes structure – forms of life and levels of organization – but sometimes ecological and evolutionary functions or processes are also included in a definition of biodiversity. For example, The Wildlife Society (1993) defined biodiversity as "the richness, abundance, and variability of plant and animal species and communities and the *ecological processes that link them with one another and with soil, air, and water"* (emphasis added).

The diversity of ecological functions is enormous. First, each of the Earth's millions of species interacts with other species through ecological processes such as competition, predation, parasitism, mutualism, and others. To take a close example, consider the staggering array of interactions between our human bodies and the more than 10,000 species of microorganisms living in or on us, each also interacting with one another (Huttenhower et al. 2012). Second, every species interacts with its physical environment through processes that exchange energy and elements between the living and nonliving world such as photosynthesis, biogeochemical cycling, and respiration. All of these functional interactions must total in the billions. The diversity of evolutionary functions is even more complex. It includes all these ecological processes because they are key elements of the conditions under which individuals survive and reproduce or do not (that is, natural selection), in addition to processes such as genetic mutation that shape each species' genetic diversity.

Functional biodiversity is clearly important. For example, a management plan designed to keep an ecosystem intact will almost certainly fail in the long run unless the processes of evolution, especially natural selection, continue, allowing the species that comprise the ecosystem to adapt to a changing environment. Sometimes, focusing on a functional characteristic, for example, the fire regime of a grassland rather than the species that comprise the grassland (Fuhlendorf et al. 2012), is the most efficient way to maintain biodiversity of an ecosystem. Nevertheless, conservation biologists usually focus on maintaining structural biodiversity rather than functional biodiversity for two reasons. First, maintaining structural biodiversity is usually more straightforward because it is easier to inventory and protect species than their interactions with one another. Second, if structural diversity is successfully maintained, functional biodiversity will probably be maintained as well. If we can maintain a species of orchid and its primary insect pollinator together in the same ecosystem, then we will almost certainly have a pollination interaction between the two. Similarly, if we can maintain the orchid's genetic diversity, we will probably have orchid evolution. The converse is not necessarily true. It is easy to think of circumstances where some major ecological processes are maintained, but structural diversity is severely degraded. For example, many of the forests of Puerto Rico are dominated by exotic trees that have largely replaced the native species, but they still perform as forests in terms of photosynthesis, biogeochemical cycling, and hydrologic processes (Lugo 2004).

In short, both the structural and functional aspects of biodiversity are important; however, if genetic, species, and ecosystem diversity are successfully maintained, then ecological and evolutionary processes will probably be maintained as well.

Measuring Biodiversity

It is easy to provide a simple definition of biodiversity such as "the variety of life in all its forms and at all levels of organization," but this is only a starting point. To monitor biodiversity and develop management plans, we should have a quantitative definition that allows us to measure biodiversity at different times and places.

The first step in measuring biodiversity is to determine which elements of biodiversity are present in the area of interest. Ideally, we would have a complete inventory, including genes, species, and ecosystems. In practice, logistical constraints commonly limit us to a partial list of species, often listing only vertebrates and perhaps vascular plants and a few large invertebrates. (Sometimes a list of ecosystems is compiled, although the basis for distinguishing among the different types is often unclear; we will focus on the species level of biodiversity here for simplicity.) Lists can be tallied to provide a crude index of biodiversity. In Table 2.1, for example, ecosystem A is easily recognized as more diverse than B or C because it has four species instead of three. This characteristic is called *species richness* or just richness, and it is a simple, commonly used measure of diversity.

Ecosystem A	Ecosystem B	Ecosystem C
Black oak	Black oak	Black oak
White pine	White pine	White pine
Red maple	Red maple	Red maple
Yellow birch		

Table 2.1 Hypothetical lists of species for three ecosystems.

Ecosystem	A	B	C
Black oak	40	120	80
White pine	30	60	60
Red maple	20	20	60
Yellow birch	10		
Richness	4	3	3
Evenness	0.92	0.88	0.99
H	0.56	0.39	0.47

$H = -\Sigma p_i \log p_i$, where p_i is a measure of the importance of the *i*th species.
Evenness = H/H_{max} where H_{max} is the maximum possible value of *H*.

Table 2.2 Abundance of species (number/hectare) in three ecosystems and measures of richness, evenness, and the Shannon diversity index (*H*), one of many ways to combine richness and evenness quantitatively. (Magurran 2004)

Ecologists also recognize a second component of species diversity called *evenness*, which is based on the relative abundance of different species. In Table 2.2 ecosystem C is more diverse than B because in C the three species have similar levels of abundance, or high evenness. The concept of evenness is not as intuitively obvious as the idea of richness. It may help to think of a jury that has five women and five men versus one that has eight women and two men; the five plus five jury is more diverse because it is more even. Note that no ecosystem ever has perfect evenness; typically there are some common species and many more uncommon species. Concern arises when uncommon species become even rarer, potentially to the point of local extinction.

The ecological importance of species richness seems quite evident, especially if you consider the loss of richness through extinction. Similarly, most conservation biologists would be concerned about any process that reduced evenness, because this would mean uncommon species are becoming less common, while common species are becoming more common. To return to our jury metaphor, this would be analogous to losing a man from the jury that only had two men. Richness and evenness are often combined into a single index of diversity using mathematical formulae (Table 2.2) but, as we will see in the next sections, such indices are of limited utility.

The Mismeasure of Biodiversity

Often, being precise and quantitative will reveal solutions to a difficult problem, but using quantitative indices of diversity can be misleading when maintaining biodiversity is the goal. Consider the following three lists of species, each one representing (in very abbreviated form) a sample of the species found in three different types of ecosystems.

Forest	**Marsh**	**Grassland**
Black oak	Reed-grass	White prairie-clover
American toad	Painted turtle	Horned lark
Eastern racer	Red-winged blackbird	Black-footed ferret
Scarlet tanager	Muskrat	
Raccoon		

If someone were asked which of these tracts is most important from the perspective of maintaining biodiversity, one measure of biodiversity – species richness – would suggest that the forest be chosen. However, if you knew that the black-footed ferret is one of the rarest mammals in the world and that all the other species listed are very common, you might well select the grassland tract. Why?

The simple answer is that all species may count the same when tallying species richness, but conservationists almost always consider additional information such as the likelihood of a species becoming extinct, its role in an ecosystem, and more. Consequently, not all species are equal from a conservation perspective. We will return to this issue in other chapters, but we need to build a foundation here by considering how conservation decisions are shaped by patterns of diversity and risk of extinction at different spatial scales.

Biodiversity and Spatial Scales

Extinction usually refers to the disappearance of a species from the Earth, but the term is also routinely used, with modifiers, to describe the disappearance of a species from a smaller area. For example, when a species disappears from a small area, this is called a *local extinction,* even though the area may later be recolonized by immigrants, e.g. when beavers return to a valley from which they had disappeared. On a somewhat larger scale one can refer to *regional extinction*. For example, during the last century the bald eagle went extinct in many regions of the United States while remaining abundant in Alaska. Although conservation biologists are most concerned about global extinctions, smaller-scale extinctions are also of some concern because they may foreshadow extinctions on a larger scale and because they may represent a loss of genetic diversity. Another key term is *endemic*, which refers to species found only in a defined geographic area; thus, koalas are endemic to Australia. If a species is found only in a very limited area (e.g. inhabiting only a single small island or lake), it is sometimes called a *local endemic*. For example, there is a snail known only from the base of a single waterfall in Chittenango, New York – the Chittenango ovate amber snail.

The risks of extinction at different spatial scales are a key consideration when deciding which endangered species are a higher priority. The larger the scale at which an extinction is likely to occur, the more important it is to try to prevent it. For example, the Iberian lynx, a species confined to southern Spain, is a higher priority for Spanish conservationists than the Eurasian lynx, which has a huge range that just reaches northern Spain (Fig. 2.2).

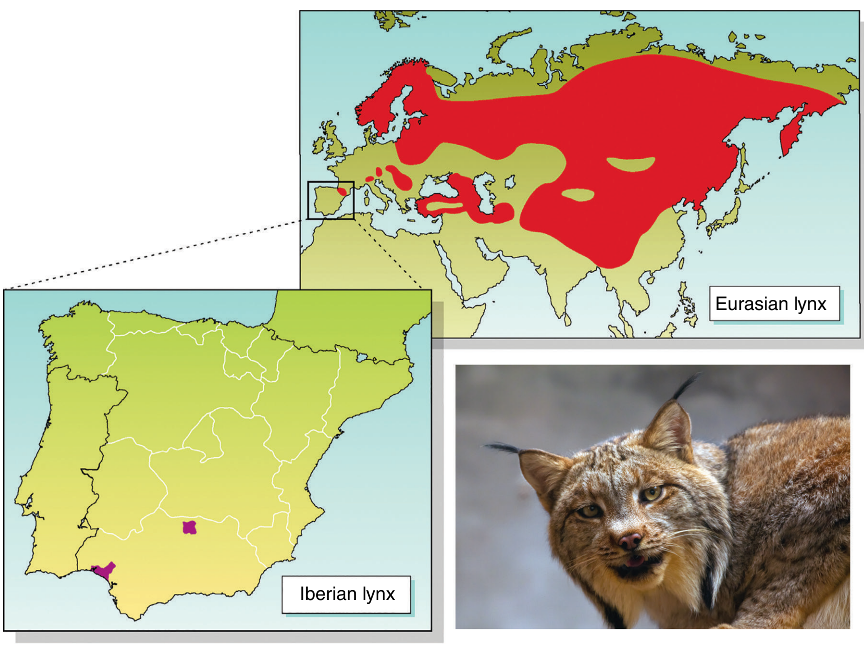


Figure 2.2 Conservationists do not consider all species to merit equal attention. For example, Spanish conservationists place a higher priority on protecting the Iberian lynx, a species now endemic to southern Spain that faces global extinction, than on the Eurasian lynx, a species threatened with regional extinction from the Pyrenees Mountains along the Spanish–French border but still relatively secure in other parts of Europe and Asia. (Apple2499/Shutterstock)

The ecologist Robert Whittaker (1960) devised a simple system for classifying the scales at which species diversity occurs: alpha, beta, gamma (A, B, C in Greek). *Alpha diversity* is the diversity that exists within an ecosystem. In Fig. 2.3 two hypothetical lizard species, spotted lizards and long-tailed lizards, illustrate alpha diversity by coexisting in the same forest, living at different heights within the forest. A third species, banded lizards, illustrates *beta diversity* (among ecosystems diversity) by occurring in a nearby field. Finally, if you imagine spotted, long-tailed, and banded lizards living on one island, and a fourth species, speckled lizards, living a thousand kilometers away on another island, this would represent *gamma diversity,* or geographic-scale diversity, that is, the total number of lizard species among all the ecosystems in question.

We can use this hypothetical example to show how a narrow-scale perspective on maintaining biodiversity can lead would-be supporters of biodiversity astray. Some people might look at Fig. 2.3 and think, "There are more lizard species in forests, so let's plant trees in the field." By doing so they might increase the alpha diversity of the field from one lizard to two (from banded lizards to spotted and long-tailed lizards), but they might also decrease the beta diversity of the island from three species to two because banded lizards would no longer have any suitable habitat. Similarly, they might think, "Let's bring some of the speckled lizards from the other island to our forest and have four species here." However, the speckled lizards might outcompete and replace one of the local lizards or introduce a disease. The whole archipelago could end up with only three, two, or one lizard species instead of four and thus decreased gamma diversity.

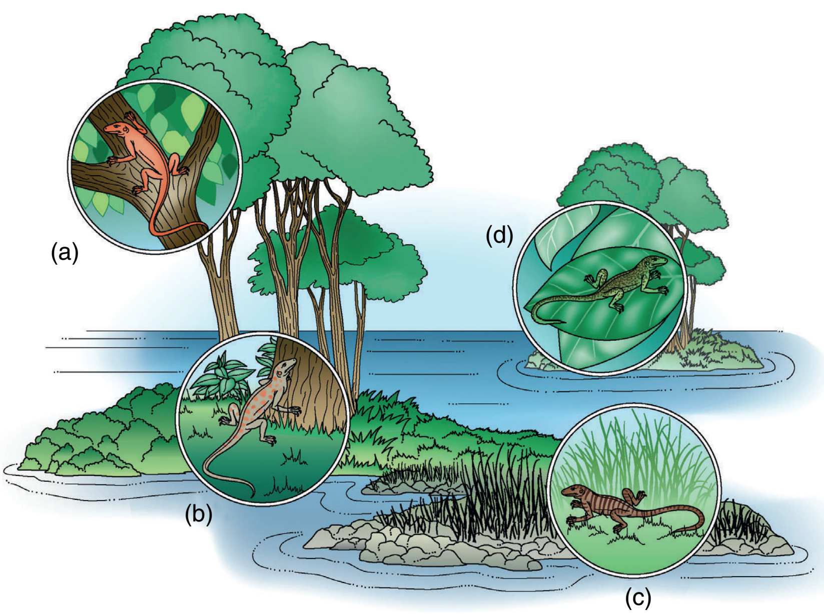


Figure 2.3 The distribution of four hypothetical lizard species showing alpha diversity (within an ecosystem, a plus b), beta diversity (among ecosystems, a/b plus c), and gamma diversity (geographic scale, a–c plus d). See text.

The idea of spatial scale is so fundamental to maintaining biodiversity that a mnemonic phrase is worth remembering: "Scale is the tail that *w-a-g-s* biodiversity" (*w*, within ecosystem diversity; *a*, among ecosystem diversity; *g-s*, geographic-scale diversity).

Diversity components usually vary dramatically from one scale to another, but not always. Take the extreme case of the native flowering plants of Antarctica. They include just two species – a grass, *Deschampsia antarctica*, and a cushion-forming plant, *Colobanthus quintensis* – that usually co-occur at the same sites. This is a very rare case where alpha and gamma diversity are the same. Or think about Madagascar with its high alpha diversity (many species at a given site), diverse ecosystems (high species turnover among ecosystems or beta diversity), and very high levels of endemism. In short, alpha and beta diversity and Madagascar's unique contribution to gamma diversity make it a global priority for conservation.

Some readers may think that some intuitively obvious ideas are being belabored here, but these ideas are frequently overlooked in the real world of natural resource management. For example, foresters who manage large tracts of contiguous forest often claim that they can increase the biodiversity of their forest by logging moderate-sized patches in their forest (Hunter and Schmiegelow 2011; Mayor et al. 2012). This claim is usually true; cutting a few patches in a mature forest typically increases species richness by increasing beta diversity because it will provide new habitat for many early successional species, while most of the species associated with a mature forest ecosystem will persist in the remaining uncut forest. On the other hand, building logging roads fragments forests and may facilitate access for excessive hunting and invasive species. These threats (to which we will return in later chapters) will probably diminish populations of some uncommon species and thus decrease evenness. Local extinction of some sensitive species is possible. Would this be a good tradeoff for increasing the beta diversity of a forested landscape? In sum, whenever we manipulate diversity at a local scale, we should consider the consequences at a larger scale and not rely on simple measurements of local biodiversity to judge the outcome. Case study 2.1 illustrates this issue well.

CASE STUDY 2.1

Clear Lake

In northwestern California lies Clear Lake, a large body of water (17,760 ha) that is shallow, warm, and productive; thus it supports a great abundance of fish. Originally, Clear Lake was home to 14 native kinds of fish, at least three of which were endemic to the lake: the Clear Lake splittail, Clear Lake hitch, and Clear Lake tule perch (Moyle 1976a; Thompson et al. 2013) (Fig. 2.4). However, beginning in the late 1800s and continuing through the 1980s, people tried to increase the fish diversity of the lake by importing exotic species, primarily sport fish sought by anglers. Stocking began with carp and two species of catfishes and continued at irregular intervals, primarily with members of the Centrarchidae family (sunfishes and basses) native to the eastern United States. One species introduced in 1967, the Mississippi silversides, soon became the most abundant species in the lake. In the face of this competition and some other issues, all of the native species have declined dramatically, and only six native species may remain common in the lake. Worse still, two of the native species that have disappeared from the lake (the Clear Lake splittail and the thicktail chub) are globally extinct. The net scorecard: misguided attempts to enrich the fish fauna of Clear Lake increased the number of fish species there from 14 to 30 by adding 26 exotic species, but these introductions have decimated the lake's native fish fauna, eliminating two elements of biodiversity from the entire planet and reducing gamma diversity. Most conservation biologists would argue that this was not a good trade. Recently some conservation biologists have disagreed about the relative importance of alpha versus gamma diversity (or, as more generally expressed, local versus global species richness), primarily because they believe that ecosystem function is more important than the nativeness of the biota (Primack et al. 2018).

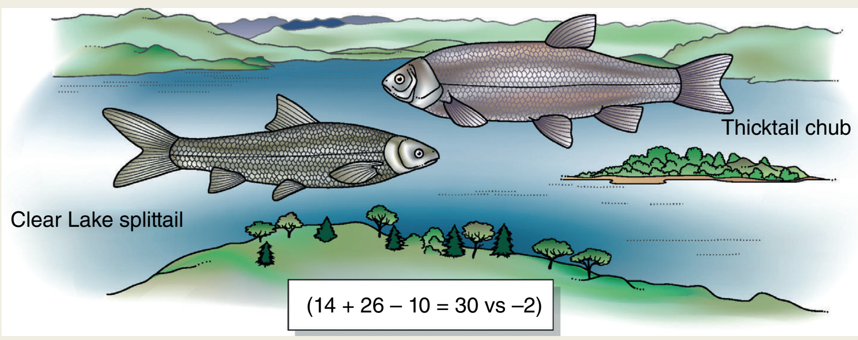


Figure 2.4 Clear Lake in northern California used to be inhabited by 14 native species of fish until fisheries managers began introducing new fish species, 26 in all. These introductions decimated the native fish populations, but still produced a net increase in alpha diversity of 16 species. This increase came at the expense of gamma diversity at a global scale because two of the original species, the Clear Lake splittail and the thicktail chub, are now globally extinct.

Biodiversity Verbs

People change, manipulate, and manage the world, and consequently affect biodiversity, often negatively. Conservationists promote positive actions and use a variety of verbs to describe these activities. The verb *maintain* is dominant in this book because a major goal of conservation biology is to keep all the elements of biodiversity on Earth, despite human-induced threats. In this section we will evaluate some alternative verbs that are often encountered in the conservation biology literature. This may seem like a pedantic exercise, but some verbs carry implications that are not always consistent with the goal of maintaining biodiversity. For example, to *maximize* biodiversity implies manipulations such as increasing the alpha diversity of an ecosystem, even importing non-native species, without considering the consequences for biodiversity at a larger scale. Manipulating the lizard populations in Fig. 2.3 was a good example of this. To *increase* or to *enhance* biodiversity may imply the same shortsightedness, unless we are referring to an ecosystem in which biodiversity has been diminished by previous human activity and the goal is to return it to its previous state. If this is the case, it is probably best to refer to *restoring* biodiversity. *Protecting* biodiversity is similar to maintaining biodiversity but with a heavier emphasis on the negative impact of most human activities. To *preserve* biodiversity carries a connotation comparable with "protect," but it may also imply that the only way to maintain biodiversity is to isolate it from human influence as much as possible; this is not always feasible or desirable (as we shall see, many human activities support biodiversity). To *benefit* or *optimize* biodiversity is rather vague; these terms are sometimes used by people who have unusual ideas about what is beneficial or optimal, In reality, biodiversity – an ever-changing and interacting entity – has no clear "optimal" state. To *conserve* biodiversity implies using it carefully in a manner that will not diminish it in the long term. This is a reasonable goal, but it tends to overlook the idea that many elements of biodiversity have little or no instrumental value for people. Finally, to *manage* biodiversity sounds value-neutral, but in practice values usually drive managers to maintain or restore biodiversity.

The Related Concepts of "Integrity" and "Sustainability"

"Biodiversity" is only one of several concepts that have been competing for the attention of natural resource managers in recent years; it has been joined by "sustainability," "ecosystem integrity," "biotic integrity," and others (Fig. 2.5).

Biotic integrity (or biological integrity) refers to the completeness or wholeness of a biological system, including the presence of all the elements at appropriate densities and the occurrence of all the processes at appropriate rates (Angermeier and Karr 1994), and thus it is quite similar to the concept of biodiversity. The difference is mainly a matter of emphasis. Biotic integrity emphasizes the overall balance and completeness of biological systems, while biodiversity emphasizes that all the biotic elements are present. Furthermore, biotic integrity gives almost equal weight to functions and structure, whereas biodiversity usually emphasizes structure. For example, no one could ever claim that they had increased biotic integrity by increasing the number of fish species in Clear Lake.

Ecosystem integrity (or ecological health and integrity) refers to the status of an ecosystem. "Ecosystem integrity" is generally the preferred term because the inevitable analogy between ecosystem health and human health can be misleading (Suter 1993; Rapport 1998). To take just one example, a forest

Figure 2.5 What is the state of this Pacific kelp forest? From a biodiversity perspective we would focus primarily on having a complete set of the native species (especially any that might be in danger of disappearing from the system), as well as genetic and ecological attributes. A biotic integrity perspective would be similar, but would put more emphasis on having an appropriate density of each species and the appropriate rate of ecological processes. In terms of ecosystem integrity, the emphasis would be on the ecological processes driving this system. A focus on sustainability would center on the prospects for maintaining this system in the future. (Ethan Daniels/Shutterstock)

ecosystem that is recently burned is not necessarily unhealthy. Ecosystem integrity is broader than both biotic integrity and biodiversity because it encompasses the physical environment; for example, soil erosion and sedimentation are key aspects of ecosystem integrity and it is usually evaluated in terms of ecosystem functions, rather than the suite of species that constitute the biological portion of an ecosystem (Callicott et al. 1999). From an ecosystem integrity perspective the productivity or water quality of Clear Lake might be considered as important as the species composition of the fish fauna.

Lastly, *sustainability* is simply the ability to maintain something over time without diminishing it. In a natural resource management context, sustaining the resources that are most directly used by people – timber, fisheries, water, energy, recreational opportunities, and so on – usually comes first (de Vries 2013). The key idea here is "intergenerational equity" or, in plainer language, not messing things up for our children and grandchildren. A related idea is tied to the term "planetary boundaries," which refers to the environmental limits within which humanity can safely operate; according to Steffen et al. (2015) we are already exceeding the proposed sustainable planetary boundaries.

Obviously conservation biologists support sustaining biodiversity but they are not all comfortable with the term, partly because it implies that the status quo is a desirable state and partly because the term is primarily associated with the instrumental value of natural resources demanded by people (Newton and Freyfogle 2005a, b). For example, sustaining the sport fisheries of Clear Lake was not linked to sustaining the native fishes.

People's values are clearly reflected in their choices of what should be maintained and sustained. It is also true, but less obvious, that the ways we judge biotic and ecosystem integrity are also shaped by values (Lackey 2001). Proponents of the biotic integrity concept are quite explicit that their ideas about "all appropriate elements and occurrence of all processes at appropriate rates" are based on using natural systems as benchmarks, that is, those with little or no human influence (Angermeier and Karr 1994; Hunter 1996). For example, they would decide whether or not a particular species of catfish belongs in Clear Lake by whether it would be there without human intervention. Many biologists would share this standard, but there is nothing sacred about using a natural system as the basis for comparison. Notably, Robert Lackey (1995) has argued that "An undiscovered tundra lake and an artificial lake at Disneyland can be equally healthy." For him the key question is whether the lake is in a desired state; that is, is it satisfying human expectations? The bottom line is that to use any of these concepts, including biodiversity, requires some kind of benchmark, and the selection of benchmarks inevitably reflects human values. Values differ among people, as we will explore in depth in Chapter 15, "Social Factors," but the large majority of people prefer to live in a healthy world where clean air, clean water, and uncontaminated soils and food are the norm, …a world where tropical forests, coral reefs, and savannas still flourish.

Summary

Biodiversity is the variety of life in all its forms (plants, animals, fungi, bacteria, and other microorganisms) and at all levels of organization (genes, species, and ecosystems). Biodiversity includes these structural components, as well as functional components; that is, the ecological and evolutionary processes through which genes, species, and ecosystems interact with one another and with their environment. Conservation biologists often focus on maintaining structural biodiversity because if genetic, species, and ecosystem diversity are successfully maintained, then the diversity of ecological and evolutionary processes will probably be maintained as well.

Some elements of biodiversity can be measured with quantitative indices of diversity based on richness (the number of elements of biodiversity, usually the number of species) and evenness (their relative abundance). However, these indices can be misleading because a higher biodiversity index is not always desirable if the goal is maintaining biodiversity. It is more important to assess the risk of extinction of different species and emphasize those that are most endangered. The risk of extinction needs to be evaluated at different spatial scales (i.e. local, regional, and global), and emphasis needs to be placed on those species most at risk at the global scale because they are irreplaceable. The issue of biodiversity and spatial scale can also be addressed by thinking of diversity at three scales (alpha, within an ecosystem; beta, among ecosystems; and gamma, geographic scale) and by always assessing the large-scale consequences whenever one manipulates biodiversity at a small scale. Thinking about biodiversity at large spatial scales will often reveal that it is inappropriate to advocate maximizing biodiversity. Instead, the goals should be to maintain natural levels of biodiversity or to restore biodiversity in ecosystems degraded by human activity. The goal of maintaining biodiversity is closely related to some other goals such as maintaining ecosystem or biotic integrity and ensuring sustainability of natural resource management, all of which are driven by human values that recognize the importance of the natural world.

FURTHER READING

There is a great wealth of information about biodiversity, ranging from an easy-to-read introduction (Wilson 1992) to a lengthy online encyclopedia (Levin 2013). The three major biodiversity journals are *Conservation Biology*, *Conservation Letters*, and *Biological Conservation*, but there are many other journals also worth perusing for conservation biology topics: *Biodiversity and Conservation*, *Bioscience*, *Conservation Science and Practice*, *Diversity and Distributions*, *Ecological Applications*, *Ecology and Society*, *Oryx*, and *Pacific Conservation Biology*, to name just eight among dozens.

TOPICS FOR DISCUSSION

1. Given a choice between conserving an ecosystem that was functioning properly (as measured by productivity, nutrient cycling, and similar parameters) and one that had a complete set of native species, which would you choose? Why?
2. Is it desirable to increase alpha- and beta-scale diversity if it can be done without apparently decreasing gamma-scale diversity?
3. If you were managing a forested stream valley, would you consider putting a small dam on the stream to add a pond ecosystem to the valley? What if the pond would be inhabited by a globally endangered species of turtle?
4. Think of some places in which you have observed ecosystems change over time. How did these changes affect biodiversity? Can you identify examples of both positive and negative changes?

CHAPTER 3
Species Diversity

Imagine flocks of parrots flashing green and gold over the piedmont forests of Virginia, a raft of penguin-like birds paddling up a Norwegian fjord, or a marsupial wolf coursing kangaroos through the eucalypt woodlands of Australia. We will never see these sights because the Carolina parakeet, great auk, and thylacine are gone. And they are not alone. Almost 900 species are known to have been driven into extinction by people just since 1600 (www.IUCNredlist.org), and we can only guess at the total number of species that have disappeared because of human activities. Nothing highlights the need for maintaining biodiversity like the fate of these species and the many more that still survive yet are sliding toward extinction. Keeping the wave of species extinctions from becoming a flood is at the core of conservation biology.

In this chapter we first address two fundamental questions: what is a species and how many species are there? Then we ask, why do they matter? To this end, we explore the importance of species diversity in terms of both intrinsic and instrumental values.

What Is a Species?

When we try to classify the natural world, it seems relatively easy to recognize different species – peregrines and redwoods are readily distinguished from other birds and trees, especially compared to drawing the lines between different kinds of ecosystems and genes. Nevertheless, the question "What is a species?" is more complex than most people realize. One widely used definition, often called the biological definition, is based on reproductive isolation: "Species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups" (Mayr 1942). For example,

Fundamentals of Conservation Biology, Fourth Edition. Malcolm L. Hunter, Jr., James P. Gibbs and Viorel D. Popescu.

Companion website: www.wiley.com/Conservation-Biology4e

mammalogists classify brown bears in Eurasia and North America as the same species, even though they have been separated by the Bering Strait for about 10,000 years, because they would interbreed given the opportunity. On the other hand, American black bears and brown bears are considered separate species because they do not interbreed despite having overlapping ranges for thousands of years. Occasionally, interbreeding does occur between two apparently distinct species, and the offspring are considered hybrids. Here some difficult questions arise (Stronen and Paquet 2013; Fitzpatrick et al. 2015). How much hybridization can occur before we decide that the two parent species are really just one species? And what if the hybrid offspring form self-perpetuating populations? These issues have come to the fore as biologists work to determine if North America is inhabited by two, three, or four species of the genus *Canis* (gray wolves, coyotes, red wolves, and eastern timber wolves) and various hybrids (Stronen et al. 2012; Wilson et al. 2012; vonHoldt et al. 2016).

Questions about hybrids are more familiar to botanists than to zoologists (Mallet 2007). Look through any comprehensive list of plant species, and you will find many listings such as *Typha angustifolia* × *latifolia*, indicating that hybrids of the narrow-leaved cattail *(angustifolia)* and the broad-leaved cattail *(latifolia)* occur routinely. However, this is only the tip of the iceberg; many species of angiosperms (flowering plants), perhaps over 70%, owe their origins to hybridization (Arnold 1992; Soltis and Soltis 2009). Plant species are also harder to define in terms of reproductive isolation than animal species because they frequently use asexual reproduction, self-fertilization, polyploidy (multiple sets of chromosomes), and other variants of what we usually consider "normal" reproduction. Similarly, most microorganisms reproduce asexually, thus confounding the idea of reproductive isolation. Their extremely rapid reproduction and thus evolution adds another complexity: is the bacterium that embarks on a transoceanic voyage with a ship's crew the same species when it returns to shore weeks later? Note, too, that species definitions do not adequately represent some of life's odder forms, such as viruses, which reproduce by invading other cells and commandeering the cellular machinery, and prions, which are infectious self-reproducing proteins (and of great concern because of their impact on deer populations) (Zabel and Ortega 2017).

Evolutionary biologists and taxonomists are wrestling with these issues and have proposed many other species definitions – phylogenetic, evolutionary, genotypic, cohesion, morphological, and more (see Coyne and Orr 2004 and Hausdorf 2011 for reviews). The differences among definitions would be an academic issue except that species distinguished by different definitions do not always correspond to one another. For example, an African antelope, the klipspringer, may be one species or 11 depending on which definition you use (Heller et al. 2013). Different definitions serve different purposes, and no one of them is "best" or "correct." That said, a group of eminent conservation biologists has made a strong case for why the classic, biological definition of a species (i.e. reproductive isolation) works well in a conservation context (Frankham et al. 2012), for reasons that we consider in subsequent chapters.

The bottom line is that conservation biologists should be aware of the important implications of how we define species (Agapow et al. 2004; Mace

2004) but not allow ourselves to be paralyzed by uncertainty. Fortunately, any ambiguity about species definitions helps to highlight the importance of considering genetic diversity. In particular, sometimes conservation biologists can sidestep the definition of species and use terms such as "evolutionarily significant units," or "taxa," in their efforts to conserve both species and intraspecific groups such as subspecies, races, varieties, or even populations (Fraser and Bernatchez 2001). As we will see in Chapter 5, "Genetic Diversity," all of these units of biological organization merit some attention from conservationists.

How Many Species Are There?

Carolus Linnaeus, the Swedish biologist who founded modern taxonomy, described about 13,000 species in his 1758 opus *Systema Naturae*, but must have been well aware that this list was incomplete because in the eighteenth century much of the world remained unexplored by scientists. Today, over two centuries later, scientists have described over 1.8 million species using Linnaeus's system, to be exact 1,837,526 species as of May 2019, according to the primary source in these matters (Species 2000) (Fig. 3.1). Of course, this number grows daily and we can still only guess how many undescribed species there might be. Estimates of total species richness span from about 3 million to over 100 million, with one thoughtful analysis arriving at 8.7 million (plus or minus 1.3 million, Mora et al. 2011), but that effort was acknowledged to be inadequate for most microorganisms.

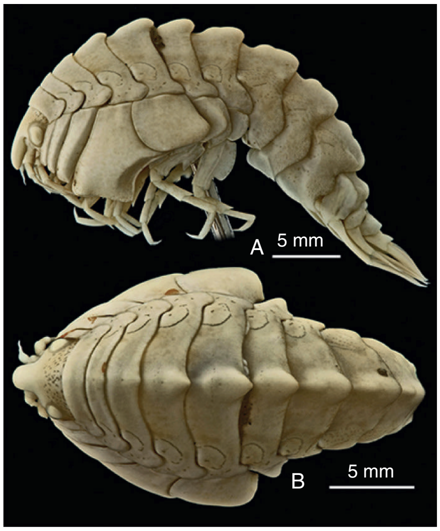
We have known for quite some time that insects represent a substantial portion of the world's biota, over half of all described species, with almost half of those insects being beetles. Biologists like to make this point with an anecdote about J. B. S. Haldane, a nineteenth-century biologist (Gould 1993). When asked by a group of theologians what he had learned about God from

Viruses	Archaea	Bacteria	Fungi	Protozoa	Algae	Plants	Arthropods	Other animals
3,186	377	9980	135,110	2,720	23,487	366,474	1,082,297	213,895

Figure 3.1 Over 1.8 million species have been described by scientists, and insects constitute over half this number. However, the estimated number of species is far greater, especially for smaller life-forms.

having spent a lifetime studying His creations, Haldane is said to have replied, "He seems to have an inordinate fondness for beetles." Although the scope for describing new beetles and other small animals remains enormous (Fig. 3.2), much of our attention in cataloging biological diversity shifted toward even smaller creatures following a classic study undertaken by a group of Norwegian microbiologists (Torsvik et al. 1990a, b). From two tiny soil samples – 1 gram of forest soil and 1 gram of marine sediment – scientists extracted first the bacteria and then the bacteria's DNA. They then estimated the diversity of DNA strands, made a conservative assumption that bacteria are different species if less than 70% of their DNA is identical, and arrived at a rough estimate that each sample contained over 4000 species of bacteria, with little or no overlap in species between the two samples. Finding over 4000 bacteria species in a pinch of Norwegian soil was doubly impressive when you realize that, in 1990, 4000 was roughly the number of species of bacteria that had ever been described from all environments in the entire world. Today the number of described bacteria species has risen to about 10,000. Estimates of undescribed species still range greatly, up into the millions (Haegeman et al. 2013), with sizable numbers coming from the *microbiome* – the enormous suite of microbes that occupy the bodies of humans and other species (Huttenhower et al. 2012).

(a)



(b)

Figure 3.2 The depth of unexplored biodiversity is greatest among small species as exemplified by this amphipod (a), recently identified from the Antarctic Ocean, or this cave beetle (b) from China (from SUNY_ESF's Top 10 New Species program: www.esf.edu/top10). Not all new species are small; in 2018 they also listed a new species of orangutan from Sumatra and a towering tree species from the coastal forest of Brazil. ([a] Cédric d'Udekem d'Acoz/Royal Belgian Institute of Natural Sciences; [b] Sunbin Huang and Mingyi Tian)

Finally, the number of species may be bolstered by the existence of *sibling species* or *cryptic species,* species that scientists cannot readily distinguish based on morphology but that are genetically distinct. Consider the case of a well-known species of butterfly, *Astraptes fulgerator*, which may be ten different species, with nearly identical adults but visibly different caterpillars feeding on different host plants (Fig. 3.3) (Hebert et al. 2004; Brower 2006; Janzen et al. 2011). The morphology of adult genitalia (a primary way to identify insect species) gave no clue to the existence of these cryptic species. The idea of cryptic diversity received lots of press attention when an undescribed species, the Atlantic coast leopard frog, most readily identified by its calls, was discovered in New York City (Feinberg et al. 2014). The species had been lurking among other leopard frog species in New York city's marshes for centuries before scientists recognized it as a unique species.

Do we really need to know how many species there are? From a conservation perspective we do not even have the resources to address adequately the problems of a few hundred well-known vertebrates and plants that are slipping toward extinction. Does it matter how many million other species we overlook? Certainly our efforts to understand ecology and evolution, the foundation of conservation biology, would be enhanced by a more complete taxonomy (Wheeler et al. 2012). And even if the number of species is of minor strategic concern, these estimates do convey two fundamental ideas. First, the number of species that may ultimately be at risk is enormous; in other words, we have a lot to lose. Second, we have a great deal yet to learn about the world.

The Intrinsic Value of Species and Their Conservation Status

Most conservationists believe that every species has intrinsic value; that is, its value is independent of its usefulness to people, to any other species, or to the ecosystem it inhabits. In other words, every species has some importance without reference to anything but its own existence (Fig. 3.4). The concept of something having value without reference to humans is not universally accepted by philosophers (Justus et al. 2009). Still, the intrinsic value of species is widely accepted among conservationists and has been embraced in important institutions like the Convention on Biological Diversity (Uggla 2010; Vucetich et al. 2015) and the US Endangered Species Act in which (in theory at least) any species can be listed for protection, no matter how obscure.

Once you accept the idea of species having intrinsic value, it is relatively straightforward to decide which species merit more attention from conservationists: they are the species most threatened with extinction. As illustrated in Boxes 3.1 and 3.2, the probability of extinction is the primary consideration for assigning species to categories of conservation status. The World Conservation Union (which is still widely known as the IUCN, the

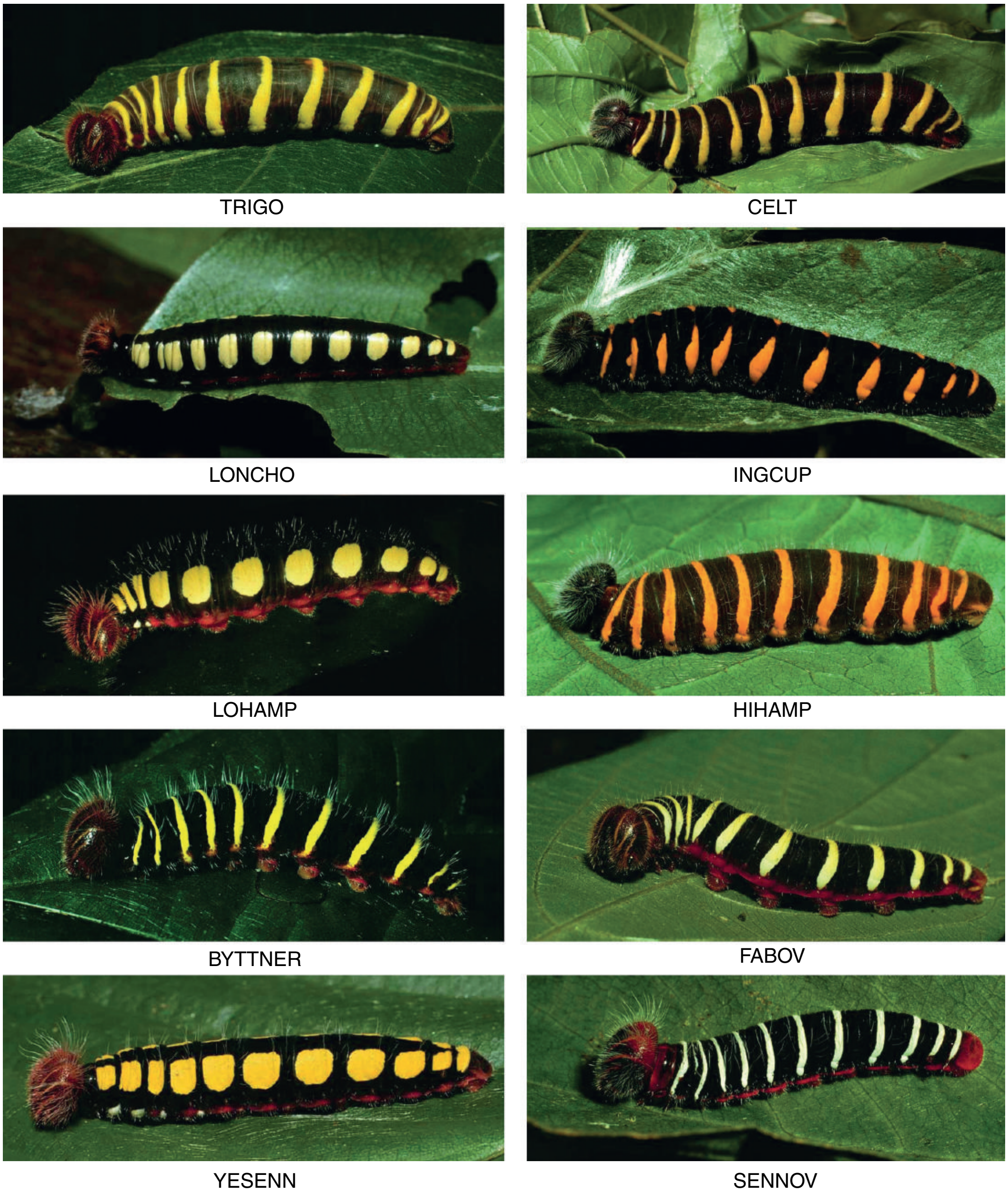


Figure 3.3 These caterpillars represent ten sibling species of what was long thought to be a single butterfly species, *Astraptes fulgerator* (Hebert et al. 2004). The interim names reflect the primary larval food plant and, in some cases, a color character. (Dan Janzen/National Academy of Sciences, U.S.A)

Figure 3.4 A species' intrinsic value is independent of its relationship with any other species as depicted on the left, whereas its instrumental value depends on its importance to other species, including people. This tree fern supports an epiphytic bromeliad that contains a small pool of water, home to many invertebrates and a breeding site for frogs. (Malcolm L. Hunter Jr., author)

initials of its former name) maintains a web-based database that lists the species that fall into these categories, commonly called the Red List (www.iucnredlist.org). This provides the primary international standard for tracking the conservation status of various species, but there are others. For example, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (cites.org) classifies endangered species into various appendices, Nature Serve (natureserve.org) maintains lists for the western hemisphere, and the Habitats and Birds Directives list all species of conservation concern in the European Union (https://ec.europa.eu/environment/nature). At a more local level, many national and state governments also maintain lists of species that are threatened within their borders (e.g. https://www.fws.gov/endangered). Sometimes, global categories are used at these local levels (e.g. Quayle et al. 2007), but more often different criteria are used, sometimes leading to very different outcomes (Harris et al.