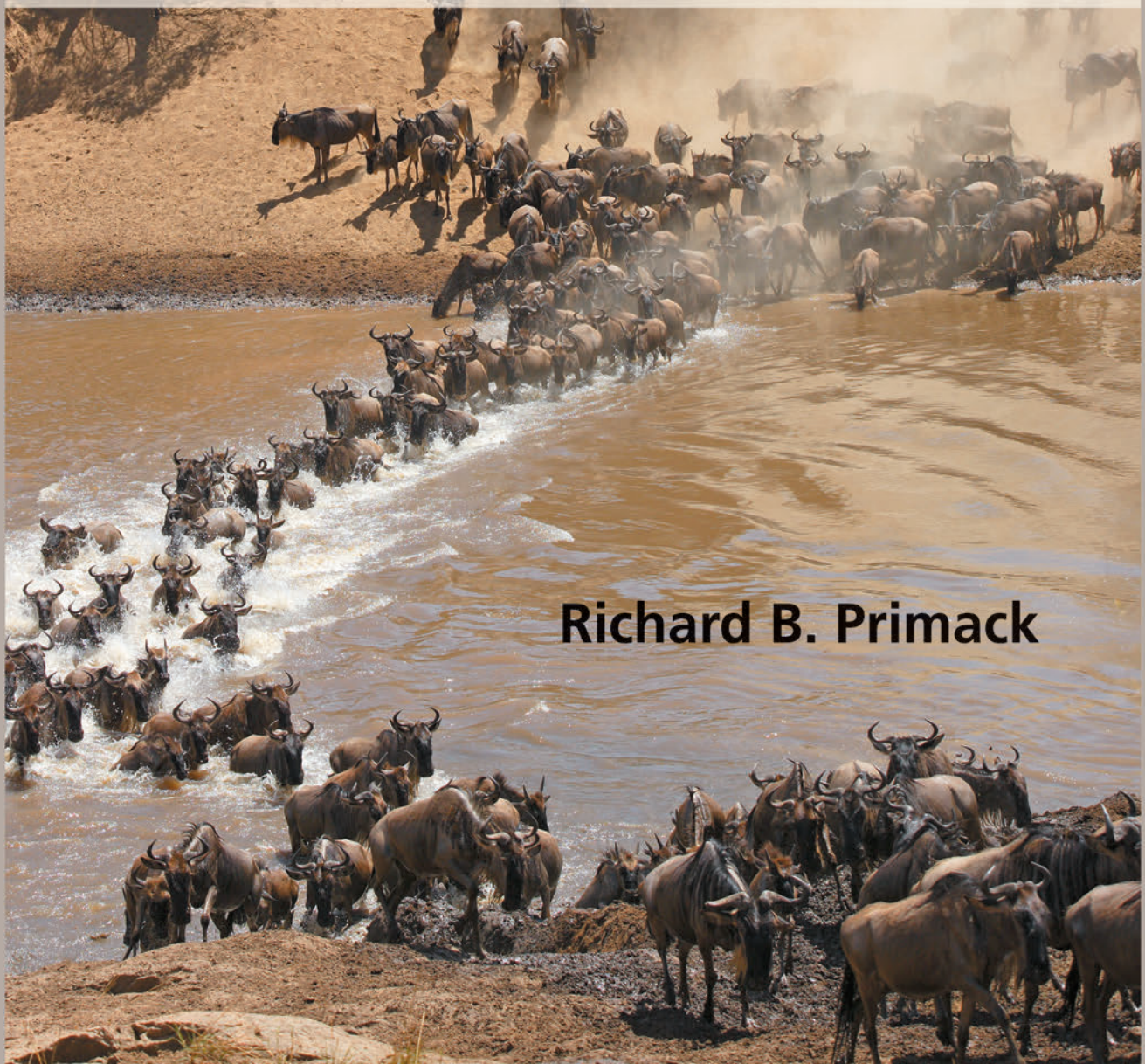
ESSENTIALS OF
Conservation Biology

Sixth Edition



Richard B. Primack

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Boston University

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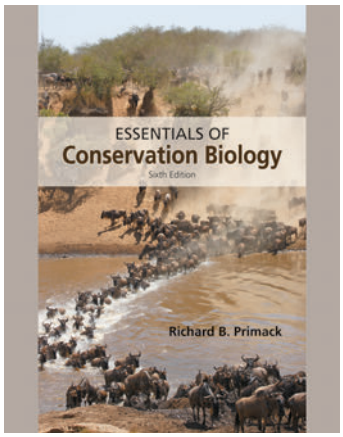

About the Cover

The Serengeti National Park in Tanzania and Maasai Mara National Reserve in Kenya protect the annual migrations of roughly 1.2 million wildebeests (*Connochaetes taurinus*), along with zebras and gazelle, from short-grass plains in the southern Serengeti to the grasslands and savannas of the Maasai Mara. Virtually the entire migration occurs within the protected areas—the only mammal migration in Africa that is completely protected.

Essentials of Conservation Biology, Sixth Edition

For information, address:
Sinauer Associates, Inc., P.O. Box 407 Sunderland, MA 01375-0407
Fax: 413-549-1118
Email: orders@sinauer.com; publish@sinauer.com
Internet: www.sinauer.com

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Rachel Morrison (1987–2014)

This book is dedicated to Rachel Morrison, a rising star in conservation biology who was passionate about the future health of the world's oceans. Rachel was the principal research assistant and organizer for the Fifth Edition and was a major contributor to the Sixth Edition, especially in topics related to marine biology. Her enthusiasm and idealism will remain an inspiration for those who were fortunate enough to know her.

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Preface

Conservation biology is the field that seeks to study and protect the living world and its biological diversity (or "biodiversity" in its shortened form). The field emerged during the last 35 years as a major new discipline to address the alarming loss of biological diversity. The threats to biodiversity are all too real, as demonstrated by the recent recognition that fully one-third of amphibian species are in danger of extinction. At the same time, we continue to be hopeful and inspired by success stories, like increasing sea turtle populations at many locations throughout the world following comprehensive conservation efforts. Many examples described in this book show that governments, individuals, and conservation organizations can work together to make the world a better place for all living things.

After decades of public interest in nature and the environment, the United Nations focused worldwide attention on conservation by declaring 2011–2020 to be the Decade of Biodiversity. The general public has absorbed this message and is asking its political leaders to provide the policy changes needed to address issues of conservation. The last two years have also seen far greater interest in ocean conservation, with the establishment of three new giant marine protected areas, each over 500,000 km^2 in area. Evidence of the ever-increasing interest in conservation biology is shown by the great intellectual excitement in many journals and newsletters and the large numbers of new edited books and advanced texts that appear almost weekly. International conservation organizations are tackling conservation issues with a multi-disciplinary approach, and an *Encyclopedia of Life* is being developed as an online resource to provide the needed information for conservation issues. Popular magazines, such as *National Geographic*, frequently publish articles with conservation themes.

Large numbers of university students continue to enroll in conservation biology courses. Previous editions of *Essentials of Conservation Biology* have provided a comprehensive textbook for this subject. (*A Primer of Conservation Biology*, in its Fifth Edition, continues to fill the need for a "quick" guide for those who want basic familiarity with conservation biology.) This Edition of *Essentials* provides a thorough introduction to the major concepts and problems of the field. Like its predecessors, it is designed for use in conservation biology courses, and also as a supplemental text for general biology, ecology, wildlife biology, and environmental policy courses. The book is also intended to serve as a detailed guide for professionals who require a comprehensive background in the subject. Readers should enjoy and benefit from the updated full-color illustration and photo program. Highlighted synopses of major points in the text have been added as sidebars and serve as useful study aids.

This Sixth Edition reflects the excitement and new developments in the field. It provides coverage of the latest information available on a number of topics, including the expanding system of marine protected areas and linkages between conservation and global change. It highlights new approaches culled from the recent literature on topics such as citizen science, aerial drones in conservation management, the economic value of wild pollinators, the use of environmental DNA (eDNA) in aquatic environments, and payments for ecosystem services.

In keeping with the global nature of conservation biology, I feel it is important to make the field accessible to as wide an audience as possible. With the assistance of Marie Scavotto and the staff of Sinauer Associates, I have arranged an active translation program, beginning with translations into German and Chinese in 1997. It became clear to me that the best way to make the material accessible was to create regional or country-specific translations, identifying local scientists to become coauthors and to add case studies, examples, and illustrations from their own countries and regions that would be more relevant to the intended audience. To that end, in the past 12 years, editions of *Essentials* have appeared in Arabic, Hungarian, Romanian (two editions), Spanish (with a Latin American focus), and Turkish; and the *Primer* has appeared in Brazilian Portuguese, Chinese (three editions), Czech, Estonian, French (two editions, one with a Madagascar focus), Greek, Indonesian (two editions), Italian (two editions), Japanese (two editions), Korean (two editions), Mongolian, Nepal (in English), Russian, South Asia (in English), Spanish, and Vietnamese. New editions of the *Primer* for Africa, Bangladesh, Brazil, Germany, Iran, Madagascar, South Korea, Laos, Pakistan, Serbia, and Thailand and the *Essentials* in China are currently in production. These translations will help conservation biology develop as a discipline with a global scope. At the same time, examples from these translations find their way back into the English language editions, thereby enriching the presentation.

I hope that readers of this book will want to find out more about the extinction crisis facing species and ecosystems and how they can take action to halt it. I encourage readers to take the field's activist spirit to heart—use the Appendix to find organizations and sources of information on how to help. If readers gain a greater appreciation for the goals, methods, and importance of conservation biology, and if they are moved to make a difference in their everyday lives, this textbook will have served its purpose.

Acknowledgments

I sincerely appreciate the contributions of everyone who helped make this book accurate and clear. Individual chapters in this edition were reviewed by Anna Sher, Andrew T. Smith, Dov Sax, Robert Costanza, Paul Ringold, Gregory Hitzhusen, Judy Che-Castaldo, Lian Pin Koh, Raphael Didham, Cagan Sekercioglu, Richard Griffiths, Elizabeth Crone, Timothy Smyser, Meghan Martin, Shawn Leroux, Pia Lentini, Chris Johnson, John Cox, David Wilcove, Luca Joppa, and Susan Jacobson. Les Kaufman of Boston University provided expertise on marine systems in all chapters.

Numerous people offered specialized input that helped make the boxes and case studies current and accurate. I would particularly like to recognize the contributions of Richard Corlett, Daniel Janzen, Randy Kautz, Laurie Bingaman Lackie, Craig Packer, Tom Power, Robert Simmons, and Tony Whitten.

Rachel Morrison and Abe Miller-Rushing carried out background research for the book, reviewed chapters, and wrote first drafts for many of the new boxes. Additional help was provided by Meg Boeni, Luca Russo, and Tanzia Shaheen. Danna Lockwood provided invaluable help in the production of the book, with numerous suggestions on how to make the book friendlier to student readers. Andy Sinauer, Azelie Fortier, Chris Small, David McIntyre, Joan Gemme and the rest of the Sinauer staff helped to transform the manuscript into a finished book.

Special thanks are due to my wife Margaret and my children Dan, Willow, and Jasper for encouraging me to fulfill an important personal goal by completing this book. I would like to recognize Boston University for providing me with the facilities and environment that made this project possible and the many Boston

University students who have taken my conservation biology courses over the years. Their enthusiasm and suggestions have helped me to find new ways to present this material. And lastly, I would like to express my great appreciation to my coauthors in other countries who have worked with me to produce conservation biology textbooks in their own languages, which are critical for spreading the message of conservation biology to a wider audience.

Richard Primack
Boston, Massachusetts
April, 2014

Media and Supplements to accompany Essentials of Conservation Biology, Sixth Edition

Instructor's Resource Library

Available to qualified adopters, the Instructor's Resource Library to accompany *Essentials of Conservation Biology* includes all of the textbook's figures and tables in a variety of formats, making it easy for instructors to incorporate figures into lectures and other course materials. All of the figures have been optimized for use in the classroom and are provided as both low-resolution and high-resolution JPEGs, as well as ready-to-use PowerPoint slides.

PART I

Major Issues That Define the Discipline

Chapter 1 What Is Conservation Biology?

Popular interest in protecting the world's biological diversity—including its amazing range of species, its complex ecosystems, and the genetic variation within species—has intensified during the last few decades. It has become increasingly evident to both scientists and the general public that we are living in a period of unprecedented **biodiversity*** loss. Around the globe, biological **ecosystems** that took millions of years to develop, including tropical rain forests, coral reefs, temperate old-growth forests, and prairies, are being devastated. Thousands, if not tens of thousands, of species and millions of unique populations are predicted to go extinct in the coming decades (Barnovsky et al. 2011). Unlike the mass extinctions in the geological past, which followed massive catastrophes such as asteroid collisions with the Earth and dramatic temperature changes, today's extinctions have a human face.

During the last 200 years, the human population has exploded. It took more than 10,000 years for the number of *Homo sapiens* to reach 1 billion, an event that occurred sometime around the year 1805. Estimates for 2014 put the number of humans at 7.2 billion, with a projected 9.4 billion by 2050 (U.S. Census Bureau); at this size, even a modest rate of population increase adds tens of millions of individuals each year (**Figure 1.1**). The threats to biodiversity are accelerating because of the demands of the rapidly increasing human population and

*__Biological diversity__ is often shortened to biodiversity; it includes all species, genetic variation, and biological communities and their ecosystem-level interactions.

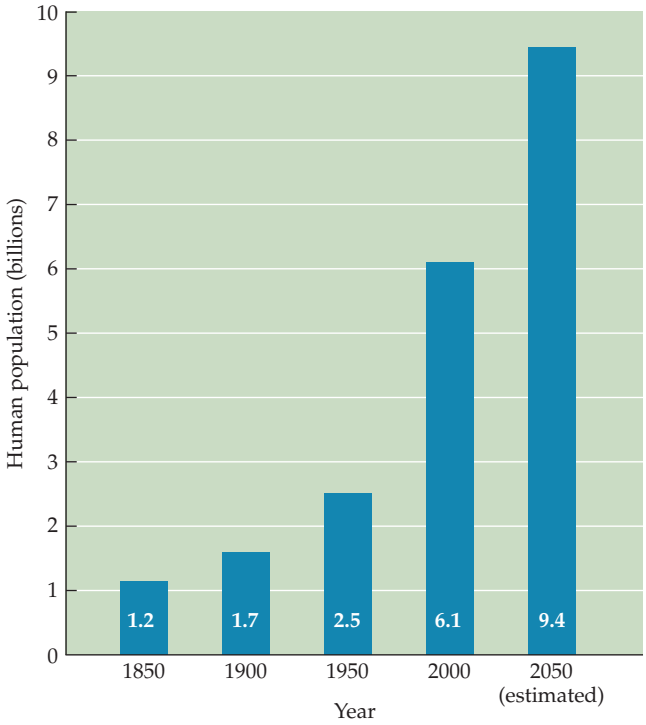


Figure 1.1 The human population in 2014 stands at around 7.2 billion. The United States Census Bureau estimates current annual population growth at 1.1%, but even this modest growth rate will add more than 78 million people to the planet in the next year. This number will escalate each year as the increase is compounded. (Data from U.S. Census Bureau, www.census.gov)

its rising material consumption. People use natural resources such as firewood, coal, oil, timber, fish, and game, and they convert natural habitats to land dominated by agriculture, cities, housing developments, logging, mining, industrial plants, and other human activities (Caro et al. 2012).

Worsening the situation is the fact that as countries develop and industrialize, the consumption of resources by their citizens increases. For example, the average citizen of the United States uses 5 times more energy than the average global citizen, 10 times more than the average Chinese citizen, and 28 times more than the average Indian citizen (Worldwatch Institute 2008; Encyclopedia of the Nations 2009). The ever-increasing number of human beings and their intensifying use of natural resources have direct and harmful consequences for the diversity of the living world (Brown et al. 2014).

Unless something is done to reverse the trend of human-caused extinctions, wonderful species that exemplify the natural world for us—such as many types of butterflies, songbirds, frogs, and whales—soon will be lost forever from their wild habitats. Additionally, many thousands, possibly millions, of less conspicuous plant, fungi, and invertebrate species and uncountable numbers of microorganisms will join them in extinction unless their habitats and populations are protected. The loss of these inconspicuous species may prove to be devastating to the planet and its human inhabitants because of the roles these species play in maintaining ecosystems. For example, the loss of soil fungi due to air pollution can lead to the death of forest trees that depend on the fungi for water and nutrient uptake.

In addition to species extinctions, the natural hydrologic and chemical cycles that people depend on for clean water and clean air have been disrupted by deforestation and land clearing. Soil erosion and pollution from agriculture and sewage discharges cause massive damage to rivers, lakes, and oceans. The very climate of our planet Earth has been disrupted by a combination of atmospheric pollution and deforestation. Genetic diversity within species has decreased as populations are reduced in size, even among species with seemingly healthy populations.

The main threat humans pose to the diversity of life is our destruction of natural habitat, which stems from the growth of the human population and our ever-increasing use of resources. Such habitat destruction includes the clear-cutting of old-growth forests in the temperate zone and rain forests in the tropics, overuse of grasslands for pasture, draining of wetlands, and pollution of freshwater and marine ecosystems. Even when parcels of natural habitat are preserved as national parks, nature reserves, and marine protected areas, extreme vigilance is required to prevent the extinction of their remaining species, whose numbers have been so dramatically reduced in the past that they are now particularly vulnerable to extinction. Also, the environment in the preserved habitat fragments may become so altered from its original condition by human activities and climate change that a site may no longer be suitable for the continued existence of certain species (see Chapter 9).

In addition to direct habitat destruction, such as those discussed above, many ecosystems have been devastated by the introduction of exotic species. Some exotic species have been deliberately brought in from other areas and established

by people, such as domesticated animals and ornamental plants, and some have been brought in accidentally, such as weed species, insect pests, and new diseases. In many cases, particularly on islands, these species have become invasive (see Chapter 10) and have displaced and eliminated native species.

Biodiversity is also threatened by the use of modern technology, which can result in overharvesting of animals and plants for local and international markets. Hunters in tropical forests now use guns and motorized vehicles, where before they used bows and arrows and walked on foot. Fishing has changed from small wind- and hand-powered boats to large motorized fleets with freezers that can stay at sea for weeks or months at a time. Entire forest, grassland, and ocean communities have been emptied of their animal life and, in many cases, cleared of their plant life as well.

Powerful technologies allow alteration of the environment on a regional and even a global scale. Some of these transformations are intentional, such as the creation of dams and the development of new agricultural land, but other changes, such as air pollution, strip-mining of entire hills, and damage to seabed habitats during fishing, are by-products of our activities. Unregulated dumping of chemicals and sewage into streams, rivers, and lakes has polluted major freshwater and coastal marine systems throughout the world and has driven significant numbers of species toward extinction. Pollution has reached such high levels that even large marine environments, such as the Mediterranean Sea, the Gulf of Mexico, and the Persian Gulf, which were once assumed to be able to absorb pollution with no negative effects, are threatened with the loss of whole suites of formerly common species. Some inland water bodies, such as the Aral Sea in Asia, have been almost completely destroyed, along with the many unique fish species that lived in them. Air pollution from factories and cars has turned rainwater into an acid solution that weakens and kills mountain trees downwind of industrial centers and, in turn, removes habitat for the animals that depend on those plants. Scientists have warned that levels of air pollution have become severe enough to alter global climate patterns and strain the capacity of the atmosphere to filter out harmful ultraviolet radiation. The impacts of these events on ecosystems are enormous and ominous; they have also stimulated the growth of conservation biology.

Scientists now realize that many of the threats to biodiversity are synergistic; that is, the negative effects of several independent factors such as logging, fire, poverty, and overhunting combine additively or even multiplicatively. Scientists also know that the threats to biodiversity directly threaten human populations because people are dependent on the natural environment for raw materials, food, medicines, and even the water they drink. And the poorest people are the ones who will experience the greatest hardship from damaged environments because they have fewer reserves of food and less access to medical supplies, transportation, and construction materials.

The New Science of Conservation Biology

Many of us feel discouraged by the avalanche of species extinctions and the wholesale habitat destruction occurring in the world today. Some would argue that we should feel challenged in order to find ways to stop the destruction (Stearns and Stearns 2010; Stockstad 2014). Actions taken—or bypassed—during the next few decades will determine how many of the world's species and natural areas will survive. People may someday look back on the first decades of the twenty-first century as an extraordinarily exciting time, when a collaboration of determined people acting locally and internationally saved large numbers of species from extinction and even entire ecosystems from destruction. Examples of such conservation efforts are described later in this chapter and throughout this book.

Conservation biology is an integrated, multidisciplinary scientific field that has developed in response to the challenge of preserving species and ecosystems. It has three goals:

1. To document the full range of biodiversity on Earth
2. To investigate human impact on species, genetic variation, and ecosystems
3. To develop practical approaches to prevent the extinction of species, maintain genetic diversity within species, and protect and restore biological communities and their associated ecosystem functions

The first two of these goals involve the dispassionate search for factual knowledge typical of scientific research. The third goal, however, defines conservation biology as a **normative** discipline; that is, it embraces certain values and attempts to apply scientific methods to achieving those values (Soulé 1985; Lindenmeyer and Hunter 2010). Just as doctors and medical researchers use knowledge gleaned from physiology, anatomy, biochemistry, and genetics to prevent illness because they value human health, conservation biologists use information from ecology, social sciences, ecological economics, and related disciplines to prevent the loss of biodiversity because they believe the preservation of species and ecosystems to be an ultimate good (Nelson and Vucetich 2009).

Conservation biology complements the traditional disciplines

Conservation biology arose in the 1980s because the traditional applied disciplines of resource management alone were not comprehensive enough to address the critical threats to biodiversity. Agriculture, forestry, wildlife management, and fisheries biology have been concerned primarily with developing methods to manage a small range of species for the marketplace and for recreation. These disciplines generally were not concerned with the protection of the full range of species and ecosystems, or at best, they regarded this as a secondary issue. Conservation biology complements the applied disciplines and provides a more general theoretical approach to the protection of biodiversity. It differs from these disciplines in its primary goal of long-term preservation of entire ecosystems, with economic factors secondary.

Conservation biology merges applied and theoretical biology and incorporates ideas and expertise from a broad range of fields outside the natural sciences, toward the goal of preserving biodiversity.

The academic disciplines of population biology, taxonomy, ecology, and genetics constitute the core of conservation biology, and many conservation biologists have been drawn from these ranks. Others come from backgrounds in the applied disciplines, such as forestry and wildlife management. In addition, many leaders in conservation biology have come from zoos and botanical gardens, bringing with them experience in locating rare and endangered species in the wild and then maintaining and propagating them in captivity. Other leaders are associated with national parks and conservation organizations.

Conservation biology is also closely associated with **environmentalism**, a widespread movement characterized by political and educational activism with the goal of protecting the natural environment from destruction and pollution. Conservation biology is a scientific discipline whose findings often contribute to the environmental movement, but it differs from environmentalism by being based in biological research (Hall and Fleishman 2010).

Because much of the biodiversity crisis arises from human pressures, conservation biology also incorporates ideas and expertise from a broad range of other fields (Reyers et al. 2010) (**Figure 1.2**). For example, environmental law and policy provide the basis for government protection of rare and endangered species and critical habitats. Environmental ethics provides a rationale for preserving species. Ecological economists provide analyses of the economic value of biodiversity to

support arguments for preservation. Ecosystem ecologists and climatologists monitor the biological and physical characteristics of the environment and develop models to predict environmental responses to disturbance. Social sciences, such as anthropology, sociology, and geography, provide methods to involve local people in conservation actions to protect their immediate environment. Conservation education links academic study and fieldwork to solve environmental problems, teaching people about science and helping them realize the value of the natural environment. Conservation organizations and national parks departments deal with the practical realities of land acquisition, park management, and fundraising. Because it draws on the ideas and skills of so many separate fields, conservation biology can be considered a truly multidisciplinary approach (Pooley et al. 2014).

A crucial difference between conservation biology and other purely academic disciplines is that conservation biology attempts to address specific issues with solutions that can be applied to actual threats to biodiversity (**Box 1.1**). These issues involve determining the best strategies for protecting rare species, designing and managing nature reserves, developing programs to maintain genetic variability in small populations, and reconciling conservation concerns with the needs of local people. The critical test for conservation biology is whether it can preserve and restore species and ecosystems. While much of conservation research remains overly academic, the goal is still to provide practical solutions that managers can use in real situations.

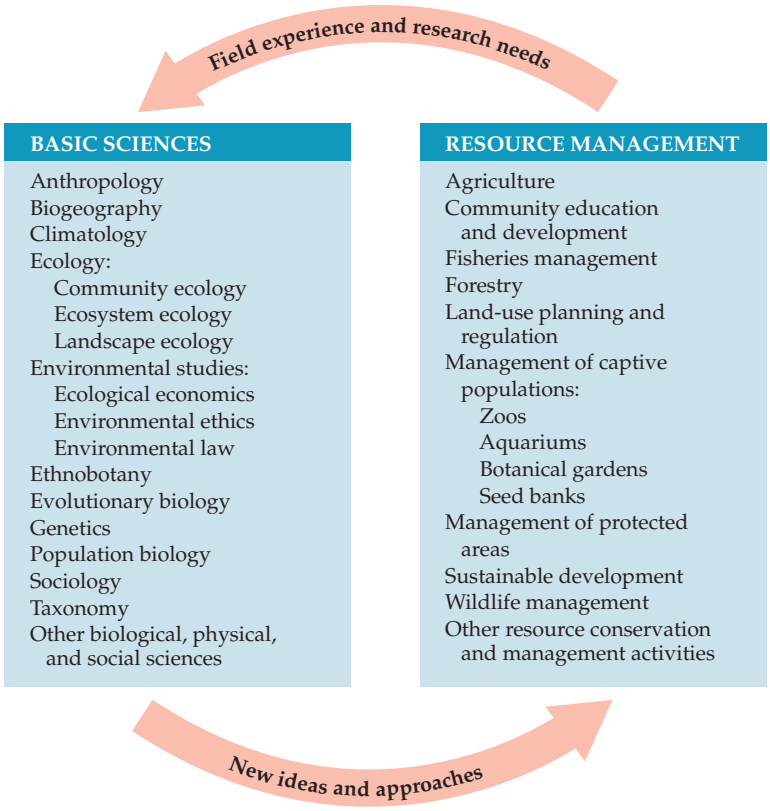


Figure 1.2 Conservation biology represents a synthesis of many basic sciences (left) that provide principles and new approaches for the applied fields of resource management (right). The experiences gained in the field, in turn, influence the direction of the basic sciences. (After Temple 1991.)

Conservation biology's ethical principles

Earlier in the chapter, we mentioned that conservation biology is a normative discipline in which certain value judgments are inherent. Conservation biology rests on an underlying set of principles that are generally accepted by members of the discipline (Soulé 1985):

- *The diversity of species and ecosystems should be preserved*. The rich diversity of life should be protected. In general, most people agree with this principle because they enjoy biodiversity. The hundreds of millions of visitors each year to zoos, national parks, botanical gardens, and aquariums testify to the general public's interest in observing different species and ecosystems (**Figure 1.3**). Genetic variation within species also sparks popular interest, as shown by the wide appeal of pet shows, agricultural expositions, flower exhibitions, and large numbers of specialty clubs (dog clubs, gardening societies, etc.). Home gardeners pride themselves on how many types of plants they have in their gardens, while bird-watchers compete to see how many species they can identify in one day or in their lifetimes. It has even been suggested that humans may have a genetic predisposition to like biodiversity, called **biophilia**, from the Greek root words *bio* or

Figure 1.3 People enjoy seeing the diversity of life, as shown by the growing popularity of butterfly gardens. (Photograph by Richard B. Primack.)

"life" and *philia* or "loving," because diverse environments provide more distinct resources that can help human survival (Corral-Verdugo et al. 2009). In addition, many people acknowledge the economic value of biodiversity.

- *The untimely extinction of populations and species should be prevented*. The ordinary extinction of species and populations as a result of natural processes is an ethically neutral event. Through the millennia of geological time, the natural extinction of species has tended to be balanced by the evolution of new species. The local loss of a population of a species, likewise, is usually offset by the establishment of a new population of that species through dispersal. However, as a result of human activity, the rate of extinction has increased by more than a hundredfold with no simultaneous increase in the generation of new populations and species (see Chapter 7). Virtually all of the hundreds of vertebrate species—and the presumed tens of thousands of invertebrate species—that have gone extinct in the last few centuries have been wiped out by human activities. Many people now recognize their role and responsibility in causing and, more important, in preventing extinctions.
- *Ecological complexity should be maintained*. Many of the most valuable properties of biodiversity are expressed only in natural environments. For example, plants with unusual flowers are pollinated by specialized insects. These relationships would no longer exist if the animals and plants were housed separately and in isolation at zoos and botanical gardens. Although the biodiversity of species may be partially preserved in zoos and gardens, the ecological complexity that exists in natural communities will be lost without the preservation of natural areas.
- *Evolution should continue*. Evolutionary adaptation eventually leads to new species and increased biodiversity. Therefore, continued evolution of populations in nature should be supported, in part by preserving genetic diversity and allowing dispersal and exchange of genetic material among populations. Although preserving endangered species in captivity is important, these species are cut

There are ethical reasons why people want to conserve biodiversity, such as a belief that species have intrinsic value. Also, people may be naturally disposed to appreciate and value biodiversity.

BOX 1.1 Collaborative Conservation: The Recovery of Kemp's Ridley Sea Turtles

Across the Gulf Coast of Texas and northeastern Mexico, government workers and volunteers patrol beaches every year from April through July (www.nps.gov/pais/naturescience/strp.htm). Their patrols are not aimed at smuggling or any other illicit activities, but rather are aimed at finding and protecting nests of the Kemp's ridley sea turtle (*Lepidochelys kempii*). The Kemp's ridley is the rarest and smallest of the world's sea turtle species, at 70–100 cm (2–3 feet) long and about 45 kg (100 pounds). This critically endangered species is now recovering as a result of international conservation efforts and teamwork.

Nearly 95% of Kemp's ridley nesting happens in the state of Tamaulipas in the northeastern corner of Mexico. In 1947, an amateur video documented an estimated 42,000 turtles coming ashore to nest on a single day at one beach. This highly synchronized nesting, or *arribada*, is unusual among sea turtles, only occurring in two species—Kemp's ridleys and olive ridleys. The highly concentrated breeding, however, makes the species particularly vulnerable to intensive harvesting. Over many decades, locals collected an estimated 80% of Kemp's ridley eggs from these Mexican beaches for eating. Thousands of turtles also drowned in fishing gear, especially in shrimp nets. In 1985 the progressive decline in Kemp's ridley populations reached a low point—there were only 702 nests worldwide. Wildlife biologists warned that this rare sea turtle species was in danger of going extinct.

Heeding this warning, government officials from Mexico and the United States worked together to help the species recover and establish stable populations. As a first step, nesting beaches were protected as refuges, reserves, and parks. Egg collection was banned. And at sea, shrimp trawlers were required to use turtle excluder devices (TEDs), a grid of bars with an opening that allows a caught turtle to escape.

In addition to reducing threats, a collaborative group of national and state agencies and conservation organizations in Mexico and the United States have undertaken an ambitious effort to increase nesting and hatchling survival and improve education and appreciation of sea turtle conservation. In the United States, park authorities began to re-establish a population on Padre Island in Texas, where the species had formerly occurred. From 1978 to 1988, scientists, conservationists, and volunteers collected 22,507 eggs from Mexico, packed them in sand, and transported them to Padre Island National Seashore, which is managed by the U.S. National Park Service. The hatchlings were released on the beach and briefly allowed to swim in the surf before they were captured using aquarium dip nets. The hope was that this brief time on the beach and in the surf would help them imprint on the site and return there to nest as adults.

Researchers collect eggs from a Kemp's ridley sea turtle nest. The eggs will be either relocated to a nest within a protected enclosure or brought to an incubation facility.

The captured hatchlings were then reared in captivity for 9–11 months as a part of a "head-start" program that allowed the turtles to grow large enough to avoid most predators. (Most sea turtles die as hatchlings.) Then the one-year-old turtles were released permanently into the Gulf of Mexico.

(Continued)

BOX 1.1 (continued)

Now, each year the staff at Padre Island, many partner organizations, and over 100 volunteers patrol the beach during the breeding season searching for Kemp's ridleys and their nests. When they find nests, teams carefully excavate them and bring the eggs to an incubation facility or a large screen enclosure called a corral. Some time later, the young hatchlings are released at public events that double as both a conservation and education tool—the hope is that the people watching each release will become advocates for their protection. Outside the National Seashore, private conservation organizations also help protect the turtles on their feeding grounds. Together these conservation activities and associated media coverage expose hundreds of thousands of visitors to information about sea turtle ecology and conservation. Over a 16-year period, the Kemp's ridley population at Padre Island National Seashore increased from 6 nests, 590 eggs, and 369 hatchlings released in 1996 to 209 nests, 20,067 eggs, and 16,577 hatchlings released in 2012. This is a dramatic increase in the population. However, in 2010 the Deepwater Horizon oil spill likely killed hundreds of Kemp's ridley sea turtles, many of them juveniles, which could negatively impact adult population size in coming years (www.nwf.org).

The core population in Mexico is also growing as a result of protections combined with public education, similar to those on Padre Island. The size of *arribada* has also increased. After reaching a low of 702 nests in 1985, researchers and volunteers counted 21,797 nests in 2012. Because each female lays two to three clutches each season, that corresponds to at least 7000–9000 mature reproducing females.

The Kemp's Ridley Recovery Sea Turtle Plan has set a target of 10,000 nesting females for the population to be considered recovered. After decades of concerted efforts, international partnerships, and the participation of volunteers and local communities, the Kemp's ridley sea turtle recovery has set an example for success that conservationist biologists are attempting to replicate for many other species in other locations.

off from the natural evolutionary processes and may not be able to survive if returned to the wild.

- *Biodiversity has intrinsic value*. Species and the ecosystems in which they live possess value of their own ("intrinsic value") regardless of their economic, scientific, or aesthetic value to human society. This value is conferred not only by their evolutionary history and unique ecological role, but also by their very existence (see Chapter 6 for a more complete discussion of this topic). This position is in sharp contrast to an economic viewpoint, which would assign a monetary value to each species or ecosystem on the basis of the goods and services that it provides or potentially could provide to humans. A purely economic viewpoint often leads to a decision to move forward with a highly destructive development project and to ignore the intrinsic value of biodiversity.

These principles cannot be proved or disproved; not every conservation biologist accepts every one, and there is no hard-and-fast requirement to do so. In fact, many conservation biologists are currently arguing for the preservation of biodiversity mainly for its contribution to human well-being. Individuals or organizations that agree with even two or three of these principles, such as religious groups and hunters, are often willing to support conservation efforts.

The Origins of Conservation Biology

The origins of conservation biology can be traced to religious and philosophical beliefs concerning the relationship between human societies and the natural world (Hitzhusen and Tucker 2013; see also Chapter 6). In many of the world's religions, people are seen as both physically and spiritually connected to the plants and animals in the surrounding environment (**Figure 1.4**). In Taoism, Hinduism, and

Figure 1.4 Tanah Lot Temple is a Hindu temple on the island of Bali in Indonesia. Its coastal setting allows worshippers to experience the connection of the human spirit with the natural world.

Buddhism, some sacred wilderness areas and natural settings are valued and protected for their capacity to provide intense spiritual experiences. Many Christian monasteries and religious centers similarly protect the surrounding environment as an important part of their mission. These philosophies see a direct connection between the natural world and the spiritual world, a connection that breaks when the natural world is altered or destroyed by human activity. Strict adherents to the Jain and Hindu religions in India believe that all killing of animal life is wrong. Islamic, Judaic, and Christian teachings are used by many people to support the idea that people are given the sacred responsibility to be guardians of nature. Many of the leaders of the early Western environmental movement that helped to establish parks and wilderness areas did so because of strong personal convictions that developed from their Christian religious beliefs.

Biodiversity often has immediate significance to traditional societies whose people live close to the land and water. In Native American tribes of the Pacific Northwest, hunters undergo purification rituals in order to be considered worthy of hunting animals. The Iroquois, a Native American group, considered how their actions would affect the lives of their descendants after seven generations. Hunting and gathering societies, such as the Penan of Borneo, give thousands of names to individual trees, animals, and places in their surroundings to create a cultural landscape that is vital to the well-being of the tribe. This type of relationship to the natural world was described eloquently at the Fourth World Wilderness Congress in 1987 by the delegate from the Kuna people of Panama (Gregg 1991):

> For the Kuna culture, the land is our mother and all living things that we live on are her brothers in such a manner that we must take care of her and live in a harmonious manner with her, because the extinction of one thing is also the end of another.

In an ecological and cultural history of the Indian subcontinent, Gadgil and Guha (1992) argue that the belief systems, religions, and myths of hunter-gatherer societies and stable agricultural societies tend to emphasize conservation themes and the wise use of natural resources because these groups have learned over time to live within the constraints of a fixed resource base. India even had the world's first documented protected areas in the third century BCE. In contrast, the belief systems of

communities that raise livestock, and rapidly expanding agricultural and industrial societies, emphasize the rapid consumption and destruction of natural resources as a way to maximize growth and assert control over other groups. These groups move to new localities when the resources of any one place are exhausted. Modern industrial states represent the extreme of such societies. Their excessive and wasteful consumption requires the transportation of resources to urban centers in ever-widening circles of resource depletion. However, what will we do when the resources are all gone?

European origins

To the European mind, the prevalent view has been that God created nature for humans' use and benefit. In Genesis, the first book of the Bible, God instructs Adam and Eve to "be fruitful and multiply and fill the Earth and subdue it; have dominion over every living thing that moves upon the Earth" (Genesis 1:28). The biblical instruction supports a dominant tenet of Western philosophy: Nature should be converted into wealth as rapidly as possible and used for the benefit of humans. This point of view justifies nearly all land uses and implies that to leave land unused is to misuse God's gift—a foolish, if not downright sinful, mistake. In medieval Europe, wilderness generally was perceived to be useless land and was often believed to be inhabited by evil spirits or monsters, in contrast to the orderly qualities and appearance of agricultural landscapes. This perspective of nature was not true in all places and in every period, but it describes a general perception that is different from a view that many of us have today.

This anthropocentric (human-centered) view of nature led to the exploitation and degradation of vast resources in the regions colonized by European countries from the sixteenth century onward (Diamond 1999). In practice, the wealth and benefits that came from this policy accrued primarily to the citizens of the colonial powers, while the needs of non-European native peoples were largely disregarded. The long-term ramifications for the forests, fisheries, and other natural resources themselves were not considered at all; the unexplored territories of the Americas, Asia, Africa, and Australia seemed so vast and rich that it was inconceivable to the colonial powers that their natural resources could ever be depleted.

An important element of the conservation movement did develop in Europe, however, based on the experiences of scientific officers—often imbued with Romantic idealism—who were sent to assist in the development of colonies in the eighteenth and nineteenth centuries (Subashchandran and Ramachandra 2008). These scientists were trained to make detailed observations on the biology, natural history, geography, and anthropology of the colonial regions. Many of them expected to find the indigenous people living in wonderful harmony with nature. Instead, they found devastated forests, damaged watersheds, and newly created poverty.

In European colonies throughout the world, perceptive scientific officers came to see that protection of forests was necessary to prevent soil erosion, provide water for irrigation and drinking, maintain wood supplies, and prevent famine. Some colonial administrators also argued that certain intact forests should remain uncut because of their necessary role in ensuring a steady supply of rainfall in adjacent agricultural areas—foreshadowing modern concern with global climate change. Such arguments led directly to conservation ordinances. On the Indian Ocean island of Mauritius, for example, the French colonial administration in 1769 stipulated that 25% of landholdings should remain forested to prevent erosion, degraded areas should be planted with trees, and forests growing within 200 meters of water should be protected. In order to prevent water pollution and the destruction of fish populations, various colonial governments passed laws in the late eighteenth century regulating the pollutants being discharged by sugar mills and other factories.

On a larger scale, British scientists working in India issued a report in 1852 urging the establishment of forest reserves throughout the vast subcontinent,

managed by professional foresters, in order to avert environmental calamities and economic losses. In particular, the report linked deforestation to decreased rainfall and water supplies, which resulted in famine among the local people. The leadership of the British East India Company, who could see that conservation made good economic sense, embraced the report. This system of forest reserves was widely adopted in other parts of the colonial world, such as Southeast Asia, Australia, and Africa, and it influenced forestry in North America as well. It is also true that many of these new systems of resource management, implemented with a top-down management style, resulted in dramatic failures when reality did not conform to management plans. A further irony is that, prior to colonization, indigenous peoples in these regions often had well-developed systems of natural resource management that were swept aside by the colonial governments (Subashchandran and Ramachandra 2008).

Many of the themes of contemporary conservation biology were established in European scientific writings of a century or more ago. The possibility of species extinction was demonstrated by the loss of wild cattle (*Bos primigenius*, also known as aurochs) from Europe in 1627 and the extinction of the dodo bird (*Raphus cucullatus*) in Mauritius in the 1680s (**Figure 1.5A**). To address the problem of the decline and possible extinction of the wisent, also known as the European bison (*Bison bonasus*), the Polish king in 1561 established a nature reserve that prohibited hunting. The Bialowieza Forest represented one of the earliest deliberate European efforts to conserve a species. While this action failed to preserve the original population of wild wisent, the wisent was reintroduced into the forest in 1951 (**Figure 1.5B**). Today the Bialowieza Forest, which extends from modern Poland into Belarus, remains one of Europe's most important nature reserves, preserving one of the last remaining stands of the great forests that formerly covered Europe.

Expression of concern for the protection of wildlife began to spread widely in Europe in the late nineteenth century (Galbraith et al. 1998). The combination of both

(A) (B)

Figure 1.5 (A) Roland Savery's figure of the dodo in his picture of the Fall of Adam, in the Royal Gallery at Berlin. This illustration was painted using a live dodo that was brought to Europe in the early seventeenth century, before the species went extinct. (B) One of Europe's first nature reserves was established to protect the wisent in Poland.

an increasing area of land under cultivation and more widespread use of firearms for hunting led to a marked reduction in wild animals. In Britain, many culturally and ecologically significant species—great bustards (*Otis tarda*), ospreys (*Pandion haliaetus*), sea eagles (*Haliaeetus albicilla*), and great auks (*Pinguinus impennis*)—became extinct in the wild around this time. Other species showed similar rapid declines. These dramatic changes stimulated the formation of the British conservation movement, leading to the founding of the Commons, Open Spaces and Footpaths Preservation Society in 1865, the National Trust for Places of Historic Interest or Natural Beauty in 1895, and the Royal Society for the Protection of Birds in 1899. Altogether, these groups have preserved about 900,000 hectares (ha) of open land (**Table 1.1** provides an explanation of the term *hectare* and other measurements).

In the twentieth century, British government action produced laws such as the National Parks and Access to the Countryside Act, passed in 1949 for the "protection and public enjoyment of the wider countryside," and the Wildlife and Countryside Act, passed in 1981 for the protection of endangered species, their habitat, and the marine environment. Because of the intensive human use of the British landscape, conservation efforts in Britain have traditionally emphasized the preservation and management of relatively small fragments of land. Rare and declining habitats, such as the chalk grasslands and old growth forests, continue to be a major concern in conservation efforts.

Many other European countries also have strong traditions of nature conservation and land protection, most notably Austria, the Netherlands, Germany, and Switzerland. In these countries conservation is both enacted by the government and supported by private conservation organizations. Over the last two decades, regional initiatives to protect species, habitats, and ecosystem processes have been coordinated by the European Union and, increasingly, by international organizations such as the World Wildlife Fund.

As demonstrated by the conservation tradition in Europe, habitat degradation and species loss can catalyze long-lasting conservation efforts.

TABLE 1.1 | Some Useful Units of Measurement

Length	
1 meter (m)	1 m = 39.4 inches = ~3.3 feet
1 kilometer (km)	1 km = 1000 m = 0.62 mile
1 centimeter (cm)	1 cm = 1/100 m = 0.39 inch
1 millimeter (mm)	1 mm = 1/1000 m = 0.039 inch
Area	
1 square meter (m^2)	Area encompassed by a square, each side of which is 1 meter
1 hectare (ha)	1 ha = 10,000 m^2 = 2.47 acres
	100 ha = 1 square kilometer (km^2)
Mass	
1 kilogram (kg)	1 kg = 2.2 pounds
1 gram (g)	1 g =1/1000 kg = 0.035 ounce
1 milligram (mg)	1 mg = 1/1000 g = 0.000035 ounce
Temperature	
°C = 5/9(°F – 32)	
degree Celsius (°C)	0°C = 32° Fahrenheit (the freezing point of water)
	100°C = 212° Fahrenheit (the boiling point of water)
	20°C = 68° Fahrenheit ("room temperature")

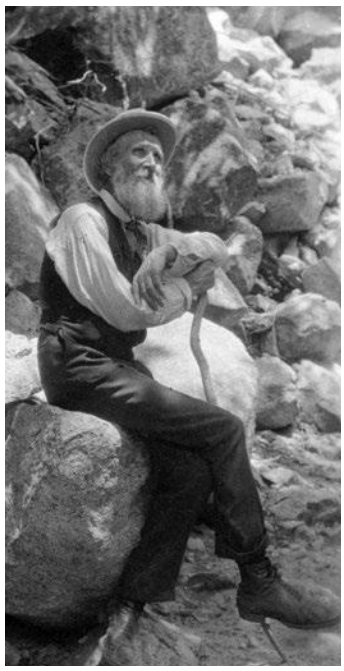
American origins

Among the first major intellectual figures in the United States arguing for the protection of natural areas were the nineteenth-century philosophers Ralph Waldo Emerson and Henry David Thoreau (Callicott 1990). Emerson, in his transcendentalist writings, saw nature as a temple in which people could commune with the spiritual world and achieve spiritual enlightenment (Emerson 1836). Thoreau was both an advocate for nature and an opponent of materialistic society, believing that people needed far fewer possessions than they sought. To prove his point, he lived simply in a cabin near Walden Pond, writing about his ideas and experiences in a book—*Walden*, published in 1854—that has had a significant impact on many generations of students and environmentalists. Thoreau believed that the experience of nature was a necessary counterweight to the weakening tendencies of civilization. In his collection of essays (1863) he argued emphatically that

> [in] wilderness is the preservation of the world. . . . The story of Romulus and Remus [the founders of the Roman Empire] being suckled by a wolf is not a meaningless fable. The founders of every state which has risen to eminence have drawn their nourishment and vigor from a similar wild source.

This concern for preserving wilderness—large areas that remain essentially unoccupied, unmanaged, and unmodified by human beings—has been a continuing and dominant theme in the American conservation movement up to the present time (Congressional Research Service and Saundry 2009). The focus on untouched wilderness stands in contrast to conservation efforts in European and other countries that seek to protect nature within a landscape that encompasses traditional uses by humans. Such focus led to the establishment of the U.S. National Park system, which includes Yellowstone, the world's first national park.

Eminent American wilderness advocate John Muir used the transcendental themes of Emerson and Thoreau in his campaigns to preserve natural areas. According to Muir's **preservationist ethic**, natural areas such as forest groves, mountaintops, and waterfalls have spiritual values that are generally superior to the tangible material gain obtained by their exploitation (Muir 1901). This philosophy emphasized the needs of philosophers, poets, artists, and spiritual seekers—who require the beauty and stimulus of nature for their development—over the needs of ordinary people, who require jobs and material goods from the natural environment. Some see Muir's view as undemocratic and elitist, arguing that it disregards the very real material needs of food, clothing, shelter, and employment, which may require economic exploitation of the wilderness. Yet one does not have to be a member of the elite in order to appreciate natural beauty: All human beings share these impulses, and Muir's arguments for the spiritual and artistic value of nature did not limit its accessibility or its benefits to a single stratum of society. That wilderness can benefit all of society can be seen today in special programs, such as Outward Bound, that use experiences with nature and wilderness to challenge and enrich the character development and self-confidence of teenagers and young adults. Over time, the importance of preserving national parks and other protected areas has been broadly accepted by the American public.



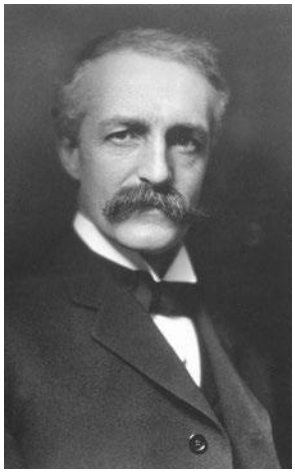
JOHN MUIR
(1838–1914)

In addition to advocating the preservation of nature on the grounds of human spiritual needs, Muir was among the first American conservationists to explicitly state that nature has **intrinsic value**—value in and of itself, apart from its value to humanity. Muir argued on biblical grounds that because God had created nature and individual species, to destroy them was undoing God's work. In Muir's view,

other species have an equal place with people in God's scheme of nature (Muir 1916, p. 139):

> Why should man value himself as more than a small part of the one great unit of creation? And what creature of all that the Lord has taken the pains to make is not essential to the completeness of that unit—the cosmos? The universe would be incomplete without the smallest transmicroscopic creature that dwells beyond our conceitful eyes and knowledge.

Muir also viewed biological communities as assemblages of species evolving together and dependent on one another, foreshadowing the views of modern ecologists.



GIFFORD PINCHOT
(1865–1946)

Gifford Pinchot, the dynamic first head of the U.S. Forest Service, developed an alternative view of nature known as the **resource conservation ethic** (Ebbin 2009). According to Pinchot, the world consists essentially of two components, human beings and natural resources. He defined natural resources as the commodities and qualities found in nature, including timber, fodder, clean water, wildlife, and even beautiful landscapes (Pinchot 1947). The proper use of natural resources, according to the resource conservation ethic, is whatever will further "the greatest good of the greatest number [of people] for the longest time." Its first principle is that resources should be fairly distributed among present individuals, and between present and future generations. In this principle, we see the origins of sustainable use doctrines and modern attempts by ecological economists to put a monetary value on natural resources. As defined by the World Commission on Environment and Development (1987), "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." From the perspective of conservation biology, **sustainable development** is development that best meets present and future human needs without damaging the environment and biodiversity (Czech 2008).

The second principle of the resource conservation ethic is that resources should be used with efficiency; that is, they should be put to the best possible use and not wasted. Efficiency implies that there can be an ordering of uses, with some favored over others, or possibly a "multiple use" of resources. In this principle, appreciation of natural beauty and other aesthetic and intellectual experiences can be considered competing uses of nature, which in some situations will take precedence over material uses, although in practice, land managers have usually given precedence to material uses even when trying to accommodate multiple uses.

Although the resource conservation ethic can be linked to resource economics to determine the "best" or most profitable use of the land, such methods use market forces to determine value and thus have a tendency to minimize or even disregard the costs of environmental degradation and to discount the future value of resources (see Chapter 4). Consequently, Pinchot argued that government bodies are needed to regulate and control natural resources such as forests and rivers with a long-term perspective to prevent their destruction. The resource conservation ethic came to dominate American thinking in the twentieth century because of its democratic social philosophy and because it supported American efforts to increase control over nature. Government bodies that manage natural resources for multiple use, such as the Bureau of Land Management and the U.S. Forest Service, are the legacy of this conservationist approach, in contrast to the generally preservationist philosophy of the National Park Service.

The resource conservation ethic was the philosophy initially embraced by the influential biologist Aldo Leopold in his early years as a government forester.

Eventually, however, he came to believe that the resource conservation ethic was inadequate because it viewed the land merely as a collection of individual goods that can be used in different ways. Leopold began to consider nature as a landscape organized as a system of interrelated processes (Leopold 1939a) and remarked:

> 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 eventually came to the conclusion that the most important goal of conservation is to maintain the health of natural ecosystems and ecological processes (Leopold 2004). As a result, he and many others lobbied successfully for certain parts of national forests to be set aside as wilderness areas (Shafer 2001). He also considered humans part of the ecological community rather than standing apart from and exploiting nature, as the proponents of the resource conservation ethic argued. Despite Leopold's philosophical shift, he remained committed to the idea that humans should be involved in land management, seeking a middle ground between overexploitation and total control over nature, on the one hand, and complete preservation of land with no human presence or activity, on the other.

Leopold's synthesis has been termed the **land ethic**. In his writings and in practice at his family farm, Leopold advocated a land use policy in which human use of natural resources was compatible with, or even enhanced, biodiversity (Leopold 1939b, 1949). Integrating human activity into preservationist philosophy makes practical sense because complete exclusion of human impact from natural reserves has always been very difficult and is now becoming impossible because of human population growth, air pollution, and global climate change. An approach known as **ecosystem management** combines ideas of both Leopold and Pinchot. This approach places the highest management priority on cooperation among businesses, conservation organizations, government agencies, private citizens, and other interested parties to provide for human needs and to maintain the health of wild species and ecosystems.

ALDO LEOPOLD
(1887–1948)

Discussions of natural resources, ecosystem management, and sustainable development are major themes throughout the field of conservation biology.

Development of these philosophies has taken place alongside the growth of many U.S. conservation organizations, such as the Wilderness Society, the Audubon Society, Ducks Unlimited, the Nature Conservancy, and the Sierra Club; the development of the national and state park systems; and the passing of numerous environmental laws. Elements of each of these differing philosophies are present in contemporary writings, the stated goals of conservation organizations, and government policy in both the United States and other countries. Disagreements over policy and practice among and within conservation organizations, individual conservationists, and government departments continue to reflect these long-term philosophical differences (Kareiva and Marvier 2012). This continuing debate over elements of conservation philosophy and ethics is necessary in deciding how to balance the long-term needs of protecting biodiversity with the more immediate needs of modern society for natural resources.

Environmental activists, writers, and educators have applied these diverse philosophies in ways that have benefited and transformed society. Ellen Swallow Richards (1842–1911) was one such influential individual, though she had great difficulty obtaining a professional position as a chemist, a field not open to women

ELLEN SWALLOW RICHARDS
(1842–1911)

RACHEL CARSON
(1907–1964)

at that time. After being appointed as chemistry instructor at the Massachusetts Institute of Technology, she developed the first course in the new subject of ecology. In her many public activities she emphasized the need to protect the natural environment as a key element in maintaining public health. Richards was particularly concerned with how water quality was affected by sewage and industrial wastes, and she began to test the quality of water in rivers and lakes. Her procedures led to the first water quality standards in the country and eventually to the development of modern sewage treatment plants that help protect public drinking supplies as well as the natural environment.

Another key figure was Rachel Carson (1907–1964). In her widely read book *Silent Spring* (1962), she documented the role of pesticides and the chemical industry in the loss of bird populations. At first she was heavily criticized by representatives of the chemical industry. However, her tireless campaigning led to bans on DDT in many countries and to better regulation of other toxic chemicals, and it was crucial to the development of the modern environmental movement. The recovery of numerous bird species, such as falcons, eagles, and ospreys, in the years following the ban on DDT proved that her observations were correct (see Box 9.1). Carson was especially effective in changing public opinion through writing popular books, some specifically written for children.

Within the American conservation movement, other writers have prophetically warned about the increasing destruction of biodiversity and the natural environment (Meine 2001). Key authors extend from G. P. Marsh, with his *Man and Nature: Or, Physical Geography as Modified by Human Action* (1864), and Fairfield Osborn, author of *Our Plundered Planet* (1948), up to former U.S. Vice President Al Gore, author of *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It* (2006), and Jared Diamond, with his decisive historical analysis *Collapse* (2005). These authors have found a receptive general audience and have galvanized citizens by the millions to join efforts to protect birds and other wildlife; to conserve mountains, seashores, wetlands, and other habitats; and to limit environmental pollution (Leisher 2008). In recent years, a new crop of writers has emerged to address growing concern with global climate change and damage to the world's oceans.

A New Science Is Born

Figure 1.6 The Society for Conservation Biology has a simple, yet powerful, logo showing the circle of life, within which we live. The ocean waves in the center symbolize the changes that lie ahead. The logo can also be viewed as a bird, which provides us with beauty; on closer look, we see that its wings are really rustling leaves. (Courtesy of the Society for Conservation Biology.)

By the early 1970s, scientists throughout the world were aware of an accelerating biodiversity crisis, but there was no central forum or organization to address the issue. The growing number of people thinking about conservation issues and conducting research needed to be able to communicate with each other to develop new ideas and approaches. Ecologist Michael Soulé organized the First International Conference on Conservation Biology in 1978, which met at the San Diego Wild Animal Park, so that wildlife conservationists, zoo managers, and academics could discuss their common interests. At that meeting, Soulé proposed a new interdisciplinary approach that could help save plants and animals from the threat of human-caused extinctions. Subsequently, Soulé, along with colleagues including Paul Ehrlich of Stanford University and Jared Diamond of the University of California at Los Angeles, began to develop conservation biology as a discipline that would combine the practical experience of wildlife, forestry, fisheries, and national park management with the theories of population biology and biogeography. In 1985, this core of scientists founded the Society for Conservation Biology (**Figure 1.6**).

Conservation biology: A dynamic and growing field

In many ways, conservation biology is a crisis discipline. Decisions about selecting national parks, species management, and other aspects of conservation are made

every day under severe time pressure (Laurance et al. 2012; Martin et al. 2013). Conservation biologists and scientists in related fields are well suited to provide the advice that governments, businesses, and the general public need in order to make crucial decisions, but because of time constraints, scientists are often compelled to make recommendations without thorough investigation. Decisions must be made, with or without scientific input, and conservation biologists must be willing to express opinions and take action based on the best available evidence and informed judgment (Maron et al. 2013). They must also articulate a long-term conservation vision that extends beyond the immediate crisis (Wilhere 2012).

Currently, conservation programs and activities are being funded as never before to address the crisis facing the world's biodiversity. For example, the Global Environment Facility, a special program established by the United Nations and the World Bank, has allocated more than $8 billion in funding and $36 billion in cofinancing for more than 2400 projects in over 165 countries involving conservation and environmental protection (www.thegef.org/gef). Major foundations, such as the MacArthur Foundation, the Ford Foundation, and the Pew Charitable Trusts, also make conservation activities a significant priority, allowing an expansion of conservation programs in developing countries.

Since its formal inception in 1985, the field of conservation biology has continued to grow in scope and influence. Conservation activities have expanded around the world, with new marine protected areas being a notable success.

The goals of conservation biology have also been adopted by traditional conservation organizations. Large, established groups such as The Nature Conservancy, the World Wildlife Fund, and Birdlife International, which formerly had a restricted set of priorities, have embraced the broader goals of conservation biology, making science central to decision making. These organizations have become international in scope, with networks of projects and personnel throughout the world. The United Nations has even decreed 2011–2020 as the Decade on Biodiversity (**Figure 1.7**).

Despite the threats to biodiversity, we can detect many positive signs that allow conservation biologists to remain cautiously hopeful (Sodhi et al. 2011). The proportion of people living in extreme poverty has been in decline since the Industrial Revolution, and the rate of human population growth has slowed (Sachs 2008). The number of protected areas around the globe continues to increase, with a dramatic expansion in the number of marine protected areas. The largest marine protected areas have all been designated within the past 5 years. Moreover, our ability to protect biodiversity has been strengthened by a wide range of local, national, and international efforts. Certain endangered species are now recovering as a result of conservation measures (Lotze et al. 2011). We can point to an expansion of our knowledge base and the science of conservation biology, the developing linkages with rural development and social sciences, and our increased ability to restore degraded environments. All of these suggest that progress is being made, despite the enormous tasks still ahead.

Figure 1.7 The United Nations has declared 2011–2020 to be the Decade on Biodiversity. Governments and conservation organizations have agreed to work on five strategic goals and 20 specific targets (collectively known as Aichi Targets) to halt the loss of biodiversity and protect and restore what remains. (Courtesy of the Secretariat of the Convention on Biological Diversity.)

SUMMARY

1. Human activities are causing the extinction of thousands of species, the loss of genetic variation, the disappearance of millions of populations, and the destruction of entire ecosystems. Conservation biology is a synthetic discipline that combines basic and applied research. Its goals are to describe the full range of biodiversity on Earth; to document the human impact on species, genetic variation, and ecosystems; and to develop practical approaches to prevent species extinctions, maintain genetic diversity, and protect and restore ecosystems.
2. Conservation biology draws on both scientific and religious/philosophical traditions. European scientists in the eighteenth and nineteenth centuries reacted to the destruction of forests and water pollution in their colonies by proposing some of the first environmental legislation. The decline and extinction of species in Europe led to the establishment of the first nature reserves and an active popular interest in conservation. In the United States, Henry David Thoreau and John Muir argued for the preservation of wilderness and the intrinsic value of species. Gifford Pinchot proposed developing a balance among competing natural resource needs for present and future societies, which is similar to the modern paradigm of sustainable development. Aldo Leopold advocated striking a balance between managing land for ecological processes and satisfying human needs. Rachel Carson's writings on the damage to wildlife caused by pesticides were crucial in establishing the modern environmental movement.
3. Conservation biology rests on a number of underlying assumptions that are accepted by most conservation biologists: biodiversity, including the range of species, genetic variation, biological communities, and ecosystem interactions, should be preserved; the extinction of species by human activities should be prevented; the complex interaction of species in natural communities should be maintained; evolutionary change should continue; and biodiversity has value in and of itself.
4. The conservation of biodiversity has become an international undertaking. There are many successful projects, such as the conservation of Kemp's ridley sea turtles, that indicate that progress can be made.

For Discussion

1. How is conservation biology fundamentally different from other branches of biology, such as physiology, genetics, or cell biology? How is it different from environmentalism?
2. What do you think are the major conservation and environmental problems facing the world today? What are the major problems facing your local community? What ideas for solving these problems can you suggest? (Try answering this question now, and once again when you have completed this book.)
3. Consider the public land management and private conservation organizations with which you are familiar. Would you consider their guiding philosophies to be closest to the resource conservation ethic, the preservation ethic, or the land ethic? What factors allow them to be successful or limit their effectiveness? Learn more about these organizations through their publications and websites.
4. How would you characterize your own viewpoint about the conservation of biodiversity and the environment? Which of the religious or philosophical viewpoints of conservation biology stated here do you agree or disagree with? How do you, or could you, put your viewpoint into practice?

Suggested Readings

Barnosky, A. D. and 11 others. 2011. Has Earth's sixth mass extinction already arrived? *Nature* 471: 51–57. Evidence from fossil records and modern extinction rates suggest that we are on the verge of a major extinction event.

Brown, M. L., T. M. Donovan, W. Scott-Schwenk, and D. M. Theobald. 2014. Predicting impacts of future population growth and development on occupancy rates of forest dependent birds. *Biological Conservation* 170: 311–320. As the human population continues to grown, more bird species will be threatened with extinction.

Caro, T., J. Darwin, T. Forrester, C. Ledoux-Bloom, and C. Wells. 2012. Conservation in the Anthropocene. *Conservation Biology* 26: 185–188. Even though human activities dominate large areas of the Earth, it is important to remember and plan for the many places and ecosystems where human influence is still minimal.

Diamond, J. 2005. *Collapse: How Societies Choose to Fail or Succeed*. Viking Press, New York. An eminent biologist describes patterns of environmental catastrophe that have destroyed human societies in the past and that threaten us today.

Hitzhusen, G. E. and M. E. Tucker. 2013. The potential of religion for Earth Stewardship. *Frontiers in Ecology and the Environment* 11: 368–376. There is a natural alliance between religion and conservation biology that can be a positive force.

Laurance, W. F. and 9 others. 2012. Making conservation research more relevant for conservation practitioners. *Biological Conservation* 153: 164–168. The goal of conservation biology is not just to create more knowledge but to also help protect biodiversity in the wild.

Leopold, A. 1949. *A Sand County Almanac*. Oxford University Press, New York. Leopold's evocative essays articulate his "land ethic," defining human duty to conserve the land and the living things that thrive upon it.

Lindenmayer, D. and M. Hunter. 2010. Some guiding concepts for conservation biology. *Conservation Biology* 24: 1459–1468. Ten general concepts are developed, with a web-based forum established for discussion.

Maron, M., J. R. Rhodes, and P. Gibbons. 2013. Calculating the benefit of conservation actions. *Conservation Letters* 6: 359–367. An approach to determine whether conservation projects actually achieve their intended goals.

Pooley, S. P., J. Andrew-Mendelsohn, and E. J. Milner-Gulland. 2014. Hunting down the chimera of multiple disciplinarity in conservation science. *Conservation Biology* 28: 22–32. Even as conservation biologists attempt to include a wider variety of disciplines, there are methodological and conceptual challenges to such broad approaches.

Soulé, M. E. 1985. "What is conservation biology?" *BioScience* 35: 727–734. Key early paper defining the field, and still relevant today for its emphasis on the intrinsic value of biodiversity.

Stearns, B. P. and S. C. Stearns. 2010. Still watching, from the edge of extinction. *BioScience* 60: 141–146. Many endangered species increasingly rely on human actions to prevent extinction.

Stokstad, E. 2014. The mountaintop witness. *Science* 343: 592–595. A stream ecologist changed from doing basic research to actively protecting the natural environment.

Wilhere, G. F. 2012. Inadvertent advocacy. *Conservation Biology* 26: 39–46. Conservation biologists need to be aware of their two separate roles, as scientists providing information about the threats to biodiversity, and as advocates for threatened biodiversity.

KEY JOURNALS IN THE FIELD *Biodiversity and Conservation, Biological Conservation, BioScience, Conservation Biology, Conservation Letters, Ecological Applications, Journal of Applied Ecology, National Geographic*

Chapter 2

What Is Biodiversity?

The protection of biological diversity is central to conservation biology. Conservation biologists use the term **biological diversity**, or simply **biodiversity**, to mean the complete range of species and biological communities, as well as the genetic variation within species and all ecosystem processes. By this definition, biodiversity must be considered on three levels:

1. *Species diversity*. All the species on Earth, including single-celled bacteria and protists as well as the species of the multicellular kingdoms (plants, fungi, and animals)
2. *Genetic diversity*. The genetic variation within species, both among geographically separate populations and among individuals within single populations
3. *Ecosystem diversity*. The different biological communities and their associations with the chemical and physical environment (the ecosystem) (**Figure 2.1**)

All three levels of biodiversity are necessary for the continued survival of life as we know it, and all are important to people (Levin 2001; MEA 2005). **Species diversity** reflects the entire range of evolutionary and ecological adaptations of species to particular environments. It provides people with resources and resource alternatives—for example, a tropical rain forest or a temperate swamp with many species produces a wide variety of plant and animal products that can be used as food, shelter, and medicine. **Genetic diversity** is necessary

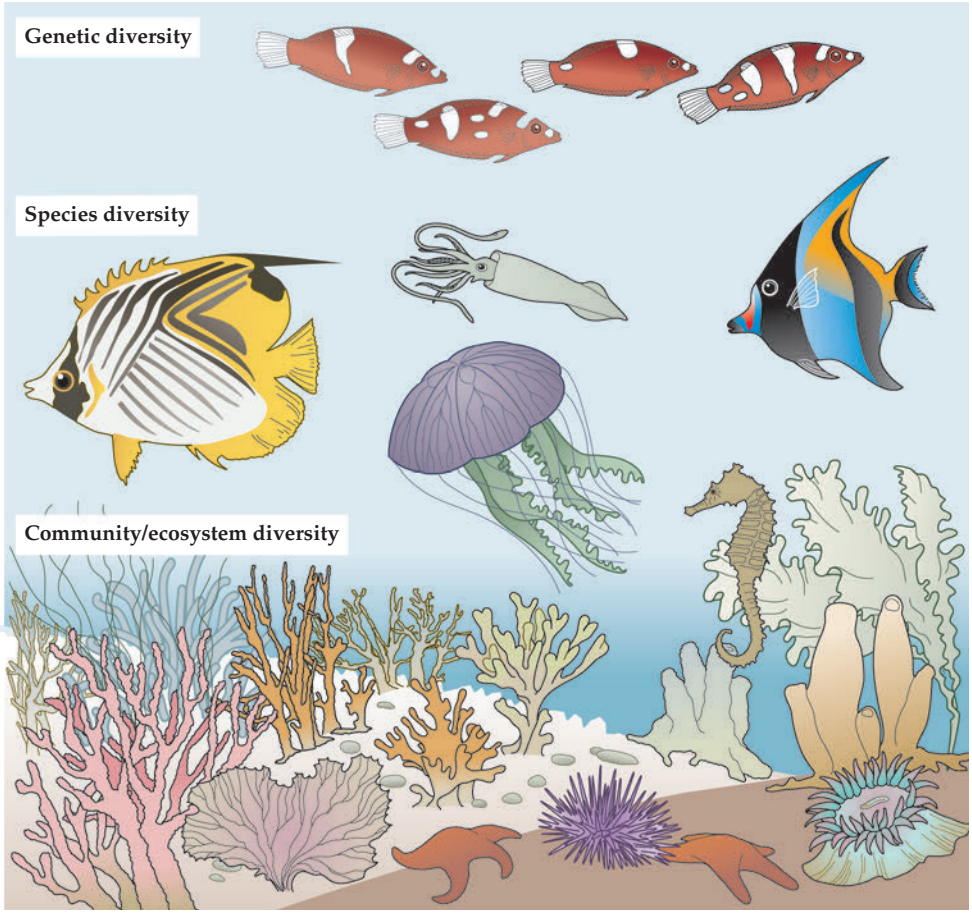


Figure 2.1 Biodiversity includes genetic diversity (the genetic variation found within each species), species diversity (the number of species in a given ecosystem), and community/ecosystem diversity (the variety of habitat types and ecosystem processes extending over a given region). (After Palumbi 2009.)

for any species to maintain reproductive vitality, resistance to disease, and the ability to adapt to changing conditions (Laikre et al. 2010). In domestic plants and animals, genetic diversity is of particular value in the breeding programs necessary to sustain and improve modern agricultural species and their disease resistance. **Ecosystem diversity** results from the collective response of species to different environmental conditions. Biological communities found in deserts, grasslands, wetlands, and forests support the continuity of proper ecosystem functioning, which provides crucial services to people, such as water for drinking and agriculture, flood control, protection from soil erosion, and filtering of air and water. We will now examine each level of biodiversity in turn.

Species Diversity

Species diversity includes the entire range of species found on Earth. Recognizing and classifying species is one of the major goals of conservation biology. How do biologists identify individual species among the mass of living organisms on Earth, many of them small in size and with few distinguishing features? And what is the origin of new species? Identifying the process whereby one species evolves into one or more new species is one of the ongoing accomplishments of modern biology. The origin of new species is normally a slow process, taking place over hundreds, if not thousands, of generations. The evolution of higher taxa, such as new genera and families, is an even slower process, typically lasting hundreds of thousands or even millions of years. In contrast, human activities are destroying in only a few decades the unique species built up by these slow natural processes.

What is a species?

A species is generally defined in one of three ways:

1. A group of individuals that is morphologically,* physiologically, or biochemically distinct from other groups in some important characteristic is the **morphological definition of a species**.
2. A group of individuals that can potentially breed among themselves in the wild and that do not breed with individuals of other groups is the **biological definition of a species**.
3. A group of individuals that share unique similarities of their DNA and hence their evolutionary past is the **evolutionary definition of a species**.

Because the methods and assumptions used are different, these three approaches to distinguishing species sometimes do not give the same results. Increasingly, characteristics of DNA sequences and other molecular markers are being used to identify and distinguish species that look almost identical, such as types of bacteria (Janzen et al. 2009).

The morphological definition of species is the one most commonly used by **taxonomists**, biologists who specialize in the identification of unknown specimens and the classification of species (**Figure 2.2**). In practice, the biological definition of species is difficult to use, because it requires a knowledge of which individuals actually have the potential to breed with one another and their relationships to each other—information that is rarely available. Similarly, the evolutionary definition requires access to expensive laboratory equipment and cannot be used in the field.

*An individual's morphology is its form and structure—or, to put it more simply (if not totally accurately), its appearance.

(A)

(B)

Figure 2.2 (A) A plant ecologist prepares a museum specimen using a plant press. The flattened and dried plant will later be mounted on heavy paper with a label giving detailed collection information. (B) An ornithologist at the Museum of Comparative Zoology, Harvard University, classifying collections of orioles: black-cowled orioles (*Icterus prosthemelas*) from Mexico and Baltimore orioles (*Icterus galbula*) that occur throughout eastern North America. (A, photograph by Richard B. Primack; B, photograph courtesy of Jeremiah Trimble, Museum of Comparative Zoology, Harvard University © President and Fellows of Harvard College.)

As a result, practicing field biologists learn to recognize one or more individuals that look different from other individuals and might represent a different species, sometimes referring to them as **morphospecies** or another such term until taxonomists can give them official scientific names (**Box 2.1**) (Norden et al. 2009).

Problems in distinguishing and identifying species are more common than many people realize (Bickford et al. 2007; Frankham et al. 2012). For example, a single species may have several varieties that have observable morphological differences, yet the varieties are similar enough to be considered a single biological species. Different varieties of dogs, such as German shepherds, collies, and beagles, all belong to one species and readily interbreed despite the conspicuous morphological differences among them. Alternatively, closely related "sibling" species appear very similar in morphology and physiology, yet they are biologically separate and do not interbreed (**Figure 2.3**). In practice, biologists often find it difficult to distinguish variation *within* a single species from variation *between* closely related species. For example, genetic analysis of New Zealand's unique reptile, the tuatara (*Sphenodon punctatus*), revealed that there are actually two distinct species of tuatara, both deserving scientific recognition and conservation protection (Hay et al. 2003). And scientists are still debating whether the African elephant (*Loxodonta africana*) is one widespread, variable species or is actually two separate species: a savanna species (*L. africana*) and a forest species (*L. cyclotis*).

Using morphological and genetic information to identify species is a major activity for taxonomists; taxonomists have only described about one-third of the earth's species.

Taxonomists are now aware that in many cases what were thought to be separate populations of the same species are in fact genetically distinct, different species. Increasingly, differences in DNA sequences and other molecular markers are being used to distinguish species that look virtually identical, including many species of bacteria, plants, and even animals. Conservation biologists and taxonomists are now developing a system that will identify the species of a living organism based on the DNA from any tissue sample, a method termed **DNA barcoding** (Valentini et al. 2009). Using such an approach, researchers found that a common small black wasp in Costa Rica that was thought to parasitize many different species of caterpillar, was actually composed of many distinct wasp species, each of which parasitized different caterpillar species (Janzen et al. 2009).

Figure 2.3 The western meadowlark (*Sturnella neglecta*; left) and the eastern meadowlark (*Sturnella magna*; right) look almost identical and sometimes even occur in the same place. However, they are distinct species because they have different songs and do not interbreed.

BOX 2.1 | Naming and Classifying Species

Taxonomy is the science of classifying living things. The goal of modern taxonomy is to create a system of classification that reflects the evolution of groups of species from their ancestors. By identifying the relationships between species, taxonomists help conservation biologists identify species or groups that may be evolutionarily unique and/or particularly worthy of conservation efforts. Information about the taxonomy, ecology, morphology, distribution, and status of species is being organized into central databases accessible via the Internet, such as the Tree of Life (www.tolweb.org). In modern classification, the following groupings apply:

- Similar species are grouped into a **genus** (plural, **genera**): the Blackburnian warbler (*Dendroica fusca*) and many similar warbler species belong to the genus *Dendroica*.
- Similar genera are grouped into a **family**: all wood warbler genera belong to the family Parulidae.
- Similar families are grouped into an **order**: all songbird families belong to the order Passeriformes.
- Similar orders are grouped into a **class**: all bird orders belong to the class Aves.
- Similar classes are grouped into a **phylum** (plural, **phyla**): all vertebrate classes belong to the phylum Chordata.

Blackburnian warblers (*Dendroica fusca*) are related to more and more other animals at successively higher levels of taxonomic organization.

(Continued)

BOX 2.1 (continued)

- Similar phyla are grouped into a **kingdom**: all animal classes belong to the kingdom Animalia.*

Biologists throughout the world have agreed to use a standard set of scientific, or Latin, names when discussing species. The use of scientific names avoids the confusion that can occur when using common names; the Latin names are standard across countries and languages. Scientific species names consist of two words. This naming system, known as **binomial nomenclature**, was developed in the eighteenth century by the Swedish biologist Carolus Linnaeus. In the scientific name for the Blackburnian warbler, *Dendroica fusca, Dendroica* is the genus name and *fusca* is the species name. The genus name is somewhat similar to a person's family name in that many people can have the same family name (Sullivan), while the species name is similar to a person's given name (Margaret).

Scientific names are written in a standard way to avoid confusion. The first letter of the genus name is always capitalized, whereas the species name is almost always lowercased. Scientific names are italicized in print or underlined when handwritten. Sometimes scientific names are followed by a person's name, as in *Homo sapiens* Linnaeus, indicating that Linnaeus was the person who first proposed the scientific name given to the human species. When many species in a single genus are being discussed, or if the identity of a species within a genus is uncertain, the abbreviations spp. or sp., respectively, are sometimes used (e.g., *Dendroica* spp. indicates several species of *Dendroica*). If a species has no close relatives, it may be the only species in its genus. Similarly, a genus that is unrelated to any other genera may form its own family.

*Until recently, most modern biologists recognized five kingdoms in the living world: plants, animals, fungi, monerans (single-celled species without a nucleus and without mitochondria, such as bacteria), and protists (more complex single-celled species with a nucleus and mitochondria). With the increasing sophistication of molecular techniques, many biologists now use a system of classification with six kingdoms within three domains: Bacteria (common bacteria), Archaea (ancient bacteria that live in extreme environments, such as hypersaline pools, hot springs, and deep sea vents), and the Eucarya (all organisms with a membrane-bound nucleus, including animals, plants, fungi, and protists).

Such a situation has been dubbed **cryptic biodiversity**—the widespread existence of undescribed species that have been wrongly classified and grouped with a similar-appearing species (Seidel et al. 2009). Using DNA technology, researchers can now distinguish hundreds of different species of bacteria in a sample of similar, tiny, nondescript cells.

To further complicate matters, individuals of related but distinct species may occasionally mate and produce **hybrids**, intermediate forms that blur the distinction between species. Sometimes hybrids are better suited to their environment than either parent species, and they can go on to form new species. Hybridization is particularly common among plant species in disturbed habitats. Hybridization in both plants and animals frequently occurs when a few individuals of a rare species are surrounded by large numbers of a closely related species. For example, the endangered Ethiopian wolf (*Canis simensis*) frequently mates with domestic dogs, and declining British populations of the European wildcat (*Felis silvestris*) are being swamped with genetic material from matings with domestic cats. In the United States, protection of the endangered red wolf (*Canis rufus*) was almost withdrawn because morphological and genetic evidence demonstrated that many of the remaining individuals are hybrids formed from extensive mating with common coyotes (*Canis latrans*) (www.redwolves.com). Even distantly related and historically isolated species may interbreed when brought into contact by humans. The endangered California tiger salamander (*Ambystoma californiense*) and the introduced barred tiger salamander (*A. mavortium*) are thought to have evolved from a common ancestor 5 million years ago, yet they readily mate in California (**Figure 2.4**). These hybrid salamanders have a higher fitness and are better able to tolerate

Figure 2.4 The hybrid tiger salamander (left) is larger than its parent species, the California tiger salamander (right), and is increasing in abundance. Note the much larger head of the hybrid salamander. (Photograph courtesy of H. Bradley Shaffer.)

environmental pollution than the native species, further complicating the conservation of this endangered species (Ryan et al. 2013).

Much more work is needed to catalog and classify the world's species. At best, taxonomists have described only one-third of the world's species, and perhaps as little as a few percent. The inability to clearly distinguish one species from another, whether due to similarities of characteristics or to confusion over the correct scientific name, often slows down efforts at species protection. It is difficult to write precise, effective laws to protect a species if scientists and lawmakers are not certain what name should be used. At the same time, species are going extinct before they are even described. Tens of thousands of new species are being described each year, but even this rate is not fast enough. The key to solving this problem is to train more taxonomists, especially for work in the species-rich tropics (Joppa et al. 2011). We'll return to this topic in Chapter 3.

The origin of new species

The biochemical similarity of all living species and the uniform use of DNA as the genetic code indicate that life on Earth originated only once, about 3.5 billion years ago. From one original species came the millions of species found on Earth today. The process of new species formation, known as **speciation**, continues today and will most likely continue into the future.

This process, whereby one original species evolves into one or more new and distinct species, was first described by Charles Darwin and Alfred Russel Wallace more than 100 years ago (Darwin 1859; Futuyma 2009). Their theory of the origin of new species is widely accepted today in the scientific community* and continues to be further refined and developed, along with the scientific disciplines of genetics and evolution. The wealth of new information that is continuously provided by the fossil record, along with the extensive modern research in molecular biology, has provided additional support for the ideas of Darwin and Wallace.

The theory of evolution is both simple and elegant. Imagine a population of a species—mountain rabbits living in Canada, for example. Individuals in the

*That the evolution of new species occurs is regarded by virtually all biologists as fact. Several popular and scholarly books (e.g., Shanks 2004; Futuyma 2009) discuss religion-based arguments (and intelligent-design arguments) against evolution and why most scientists do not accept such arguments.

population tend to produce more offspring than can survive in that place. Most offspring will die before reaching maturity. In the population, each pair of rabbits will produce numerous litters of six or more offspring, yet on average, in a stable population, only two of those offspring will survive to adulthood. Individuals in the population show variations in certain characteristics (such as fur thickness), and some of these characteristics are inherited; that is, they are passed from parents to offspring via genes. These genetic variations are caused both by mutations—spontaneous changes in the chromosomes—and by the rearrangement of chromosomes that occurs during sexual reproduction. Within the rabbit population, some individuals have thicker fur than others because of such genetic differences. These differences will enable some individuals to grow, survive, and reproduce better than others, a phenomenon sometimes referred to as survival of the fittest. Our hypothetical thick-furred rabbits will be more likely to survive cold winters than rabbits with thinner fur. As a result of the improved survival ability associated with a certain genetic characteristic, the individuals possessing that characteristic will be more likely to produce offspring than the others; over time, the genetic composition of the population will change. After a series of cold winters, more thick-furred rabbits will have survived and produced thick-furred offspring, while more thin-furred rabbits will have died. Consequently, more rabbits in the population will have thicker fur than in previous generations. At the same time, another population of the same species living in a lowland area or further south could be undergoing selection for individuals with thinner fur in response to warmer conditions.

In the process of evolution, populations often genetically adapt to changes in their environment. These changes may be biological (new food sources, new competitors, new predators) as well as environmental (changing climate, different water availability, altered soil characteristics). When a population has undergone so much genetic change that it is no longer able to interbreed with the original species from which it derives, the population can be considered a new species. This gradual transformation of one species into another is termed **phyletic evolution**.

In order for two or more new species to evolve from one original ancestor, there is usually a geographical barrier that prevents the movement of individuals between the various populations of a species (Futuyma 2009). For terrestrial species, these barriers may be rivers, mountain ranges, or oceans that the species cannot readily cross. Aquatic species adapt to particular lakes, rivers, or estuaries, which are separated from one another by land. Speciation is particularly rapid on islands where populations are small and individuals can not readily disperse from one island to another. Island groups, such as the Galápagos and the Hawaiian Islands, are homes to many examples of insects and plants that were originally local populations of a single colonizing species. These newly arrived, local populations adapted genetically over successive generations to the distinctive environments of particular islands, mountains, and isolated valleys. Often in the absence of the competitors, predators, and parasites that affected them on the mainland, once they were able to disperse across the water to a new island, they diverged sufficiently from the original species to be considered separate species. This process of local adaptation and subsequent speciation is known as **adaptive radiation**. One of the best-known examples of adaptive radiation is that of the Hawaiian honeycreepers, a group of specialized bird species that is believed to derive from a single pair of birds that arrived by chance in the Hawaiian Islands tens of thousands of years ago (**Figure 2.5**). Over this time period, honeycreeper species have evolved bill shapes and behaviors that are specialized to particular food resources.

Normally species do not appear to change from year to year, and even observant naturalists don't notice the origin of new species. The process of speciation appears to be slow and gradual. However, there are mechanisms whereby new species can arise in just one generation without geographical separation.

Figure 2.5 The Hawaiian honeycreeper family, a spectacular example of adaptive radiation, is thought to have arisen from one pair of birds that arrived on the Hawaiian Islands (indicated by #1). The shape and size of the bill are related to foods eaten: sharp for eating insects, long and thin for picking bark, thick for cracking seeds and eating fruit, long and curved for feeding on nectar, and short and sharp for eating many different items. Black lines separate different feeding habits. Different color patterns represent adaptations for mating behavior. Numbered birds indicate different species, both living and recently extinct. (Courtesy of Doug Pratt.)

Unusual, unequal divisions of chromosome sets during reproduction may result in offspring with extra sets of chromosomes; these offspring are known as **polyploids**. Polyploid individuals may be morphologically and physiologically different from their parents and, if they are well suited to the environment, may form a new species within the range of the parent species. Hybrids that result from mating between individuals of two different species can also form new species, especially when they have different characteristics from their parents and mate among themselves. New hybrid and polyploid species are particularly common in plants.

Even though new species are arising all the time, the present rate of species extinction is probably more than 100 times faster than the rate of speciation and may even be 1000 times faster. The situation is actually worse than this grim statistic suggests. First, the rate of speciation may actually be slowing down because so much of the Earth's surface has been taken over for human use and no longer supports evolving biological communities. As habitats decline, fewer populations of each species exist, and thus there are fewer opportunities for evolution. Many of the existing protected areas and national parks may be too small to allow the process of speciation to occur (**Figure 2.6**). Second, many of the species threatened with extinction in the wild are the sole remaining representatives of their genus or family; examples include the gorilla (*Gorilla gorilla*), rapidly declining throughout its range in Africa, and the giant panda (*Ailuropoda melanoleuca*) in China. The

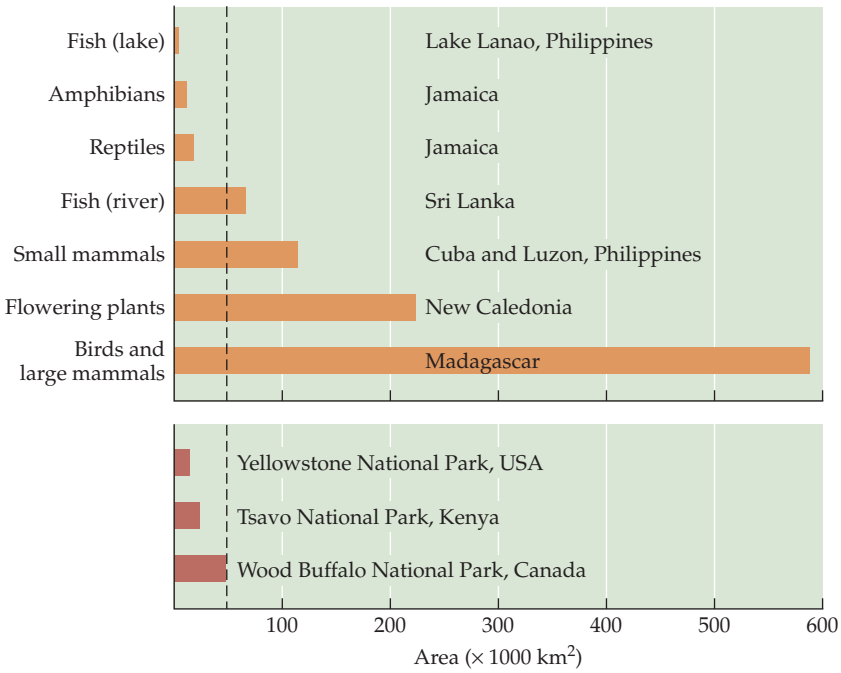


Figure 2.6 Certain groups of organisms apparently need a minimum area in order to undergo the process of speciation (upper graph). For example, for small mammals, the smallest islands (Cuba and Luzon) on which a single species is known to have given rise to two species are 100,000 km^2. The bottom graph shows the areas of some national parks. Even the largest national park shown (dotted line) is probably too small to allow for the evolution of new species of river fish, flowering plants, birds, or mammals, although it might be large enough for the continued evolution of lake fishes, amphibians, and reptiles. (After Soulé 1980.)

extinction of taxonomically unique species representing ancient lineages is not balanced by the appearance of new species that are closely related to existing species.

Measuring species diversity

Conservation biologists often want to identify locations of high species diversity. In the broadest sense, species diversity is simply the number of different species in a place, a measure often called **species richness**. However, there are many other specialized, quantitative definitions of species diversity that ecologists have developed as a means of comparing the overall diversity of different communities at varying geographical scales (Flohre et al. 2011). Ecologists have used these quantitative measures to test the assumption that increasing levels of diversity lead to increasing community stability and biomass production (Marquard et al. 2009). In controlled experiments in greenhouses or gardens, or in grassland plant communities, increasing the number of species growing together generally leads to greater biomass production and resistance to drought. The significance of this result to the broader range of natural communities, such as forests and coral reefs, is now being demonstrated (Hooper et al. 2012). Measures of biodiversity used by field ecologists are often most useful for comparing particular groups of species within or among communities and determining patterns of distribution. These researchers typically consider the diversity of plants, birds, or frogs separately.

Whereas species richness is the most basic metric of diversity, several quantitative indexes of biodiversity have been developed primarily to denote species diversity at three different geographical scales. The number of species in a certain community or designated area is described as **alpha diversity**. Alpha diversity comes closest to the popular concept of species richness and can be used to compare the number of species in particular places or ecosystem types, such as lakes or forests. For example, a 100 hectare (ha) deciduous forest in New York or England has fewer tree species than a 100 ha patch of the Amazon rain forest; that is, the alpha diversity of the rain forest is greater. More highly quantitative indexes such as the Shannon diversity index take the relative abundance of different species into account and assign the highest diversity to communities with large numbers of

species that are equally abundant and the lowest scores to communities in which there are either few species, or a large number of species, one or a few of which are much more abundant than the others.

Gamma diversity applies to larger geographical scales. It refers to the number of species in a large region or on a continent. Gamma diversity allows us to compare large areas that encompass diverse landscapes or a wide geographical area. For example, Kenya, with 1000 species of forest birds, has a higher gamma diversity than Britain, which has only 200 species.

Beta diversity links alpha and gamma diversity. It represents the rate of change of species composition along an environmental or geographical gradient. For example, if each lake in a region contained different fish species, or if the bird species on one mountain were entirely different from the birds on neighboring mounts, then beta diversity would be high. However, if the species composition along the gradient did not change much ("the birds on this mountain are the same as the birds on the mountain we visited yesterday"), then beta diversity would be low. Beta diversity is sometimes calculated as the gamma diversity of a region divided by the average alpha diversity, though other measures also exist.

Identifying patterns of species diversity helps conservation biologists establish which locations are most in need of protection.

We can illustrate the three types of diversity with a theoretical example of three mountain ranges (**Figure 2.7**). Region 1 has the highest alpha diversity, with more species per mountain on average (six species) than the other two regions. Region 2 has the highest gamma diversity, with a total of 10 species. Dividing gamma by

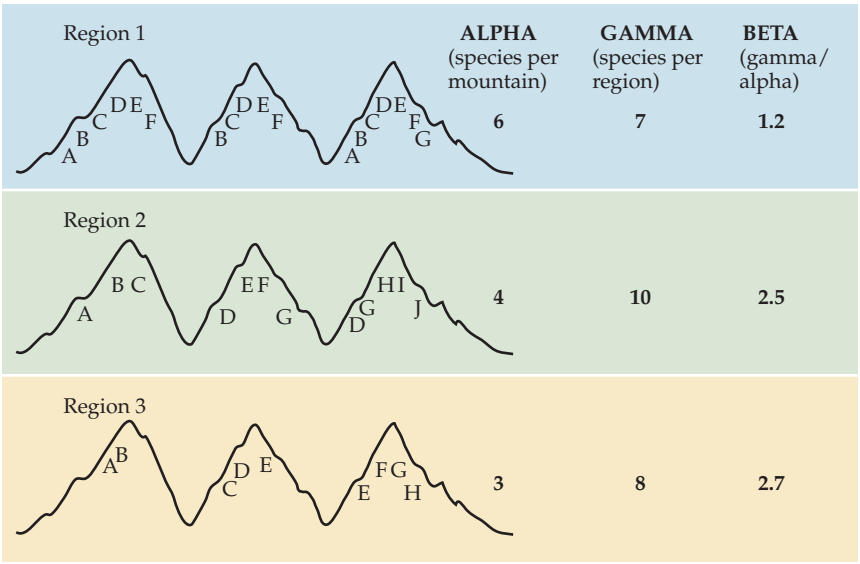


Figure 2.7 Biodiversity indexes for three regions, each consisting of three separate mountains. Each letter represents a population of a species; some species are found on only one mountain, while other species are found on two or three mountains. Alpha, gamma, and beta diversity values are shown for each region. If funds were available to protect only one mountain range, Region 2 should be selected because it has the greatest gamma (total) diversity. However, if only one mountain could be protected, a mountain in Region 1 should be selected because these mountains have the highest alpha (local) diversity; that is, the greatest average number of species per mountain. Each mountain in Region 3 has a more distinct assemblage of species than the mountains in the other two regions, as shown by the higher beta diversity. If Region 3 were selected for protection, the relative priority of the individual mountains should then be judged based on the relative rarity of the assemblages.

alpha shows that Region 3 has a higher beta diversity (2.7) than Region 2 (2.5) or Region 1 (1.2) because all of its species are found on only one mountain each.

These quantitative definitions of diversity are useful for talking about patterns of species distribution and for comparing regions of the world. They are also valuable for highlighting areas that require conservation protection. As an example, artificial wetlands in agricultural landscapes in Sweden were evaluated for their aquatic invertebrate diversity, including snails, insects, and worms. It was found that over 80% of species richness was attributed to beta diversity (many of the invertebrate species in one wetland area were unique to that wetland; Thiere et al. 2009). This result indicates that protecting many wetlands is needed, rather than focusing on just a few sites.

Genetic Diversity

At each level of biodiversity—genetic, species, and ecosystem—conservation biologists study the mechanisms that alter or maintain diversity. Genetic diversity within a species is often affected by the reproductive behavior of individuals within populations. A **population** is a group of individuals that mate with one another and produce offspring; a species may include one or more separate populations. A population may consist of only a few individuals or millions of individuals, provided that the individuals actually produce offspring. A single individual of a sexual species would not constitute a population. Neither does a group of individuals that cannot reproduce; for example, the last 10 dusky seaside sparrows (*Ammodramus maritimus nigrescens*), native to the southeastern United States, did not constitute a true population, because all of them were male.

Individuals within a population usually are genetically different from one another. Genetic variation arises because individuals have slightly different forms of their **genes** (or **loci**), the units of the chromosomes that code for specific proteins. These different forms of a gene are known as **alleles**, and the differences originally arise through **mutations**—changes that occur in the deoxyribonucleic acid (DNA) that constitutes an individual's chromosomes. The various alleles of a gene may affect the development, appearance, and physiology of an individual organism.

Genetic variation increases when offspring receive unique combinations of genes and chromosomes from their parents via the **recombination** of genes that occurs during sexual reproduction. Genes are exchanged between chromosomes, and new combinations are created when chromosomes from two parents combine to form a genetically unique offspring. Although mutations provide the basic material for genetic variation, the random rearrangement of alleles in different combinations that characterizes sexually reproducing species dramatically increases the potential for genetic variation.

The total array of genes and alleles in a population is the **gene pool** of the population, while the particular combination of alleles that any individual possesses is its **genotype** (Winker 2009). The **phenotype** of an individual represents the morphological, physiological, anatomical, and biochemical characteristics of the individual that result from the expression of its genotype in a particular environment (**Figure 2.8**). Some characteristics of humans, such as the amount of body fat and tooth decay, are strikingly influenced by the

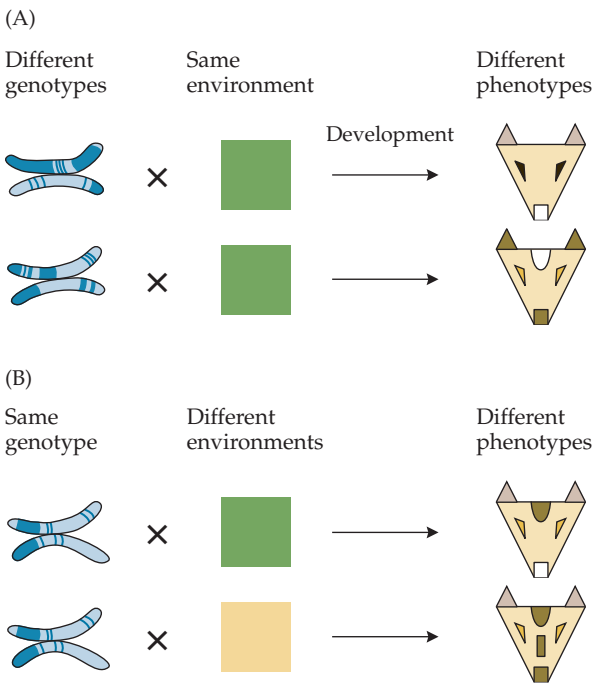


Figure 2.8 The physical, physiological, and biochemical characteristics of an individual—its phenotype—are determined by its genotype and by its environment (e.g., hot vs. cold climate; abundant vs. scarce food) in which the individual lives. (After Alcock 1993.)

environment, while other characteristics, such as eye color, blood type, and forms of certain enzymes, are determined predominantly by an individual's genotype.

Sometimes individuals that differ genetically also differ in ways related to their survival or ability to reproduce—such as their ability to tolerate cold, as in our hypothetical thick-furred rabbits; their resistance to disease; or the speed at which they can run away from danger. If individuals with certain alleles are better able to survive and produce offspring than individuals without these alleles, then **gene frequencies** in the population will change in subsequent generations. This phenomenon is called **natural selection**. Our hypothetical rabbits in the cold climate are experiencing natural selection against thin, short fur.

Genetic variation within a species can allow the species to adapt to environmental change; genetic variation can also increase the value of domestic species to people.

The amount of genetic variability in a population is determined by both the number of genes that have more than one allele (**polymorphic genes**) and the number of alleles for each of these genes (**Figure 2.9**). The existence of a polymorphic gene also means that some individuals in the population will be **heterozygous** for the gene; that is, they will receive a different allele of the gene from each parent. On the other hand, some individuals will be **homozygous**: they will receive the same allele from each parent. All these levels of genetic variation contribute to a population's ability to adapt to a changing environment. Rare species often have less genetic variation than widespread species and, consequently, are more vulnerable to extinction when environmental conditions change (Frankham et al. 2009). The importance of genetic variability to conservation biology is discussed at length in Chapter 11.

In a wide variety of plant and animal populations, it has been demonstrated that individuals that are heterozygous have greater **fitness** than comparable homozygous individuals. This means that heterozygous individuals have greater growth, survival, and reproduction rates than homozygotes. The reasons for this appear to be that (1) having two different alleles gives the individual greater flexibility in dealing with life's challenges, and (2) nonfunctional or harmful alleles received from one parent are masked by the functioning alleles received from the other parent. This phenomenon of increased fitness in highly heterozygous individuals, also referred to as **hybrid vigor** or **heterosis**, is widely known in domestic animals. As populations of wild species get smaller because of habitat destruction and other human activities, genetic variation will be lost and individuals will have a lower

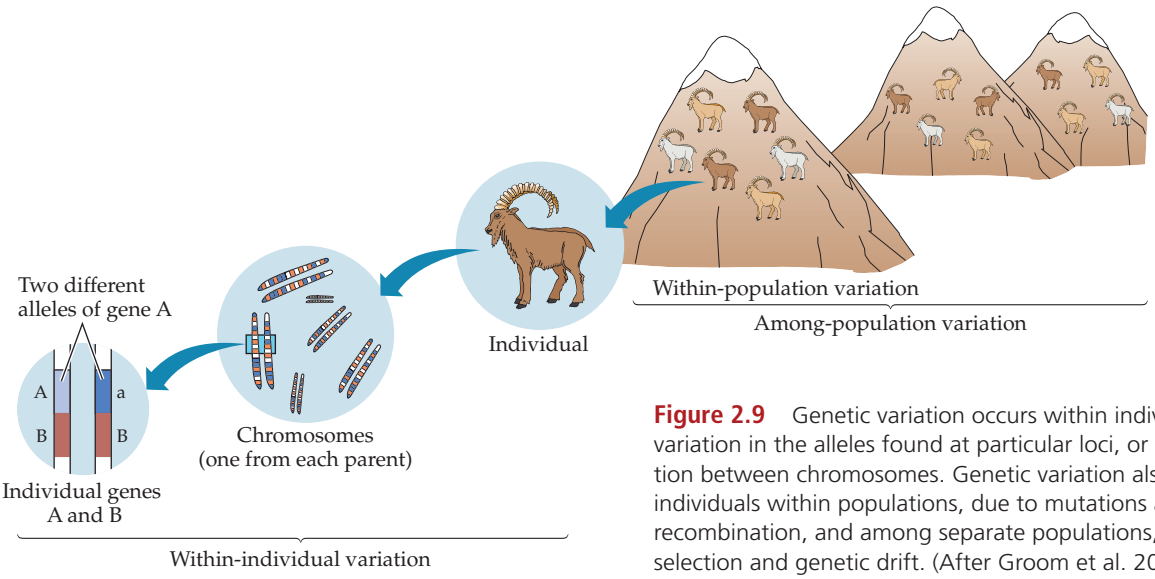


Figure 2.9 Genetic variation occurs within individuals due to variation in the alleles found at particular loci, or genes, and variation between chromosomes. Genetic variation also occurs between individuals within populations, due to mutations and genetic recombination, and among separate populations, due to natural selection and genetic drift. (After Groom et al. 2006.)

average fitness. Genetic variation within a species can also affect the abundance and distribution of other species. For example, genetic variation in bark characteristics among individuals in a widespread tree species can enhance the regional diversity of bark-inhabiting insects (Barbour et al. 2009).

Populations of a species may differ genetically from one another in relative frequencies of alleles and even in types of allele forms for particular genes. These genetic differences may result from adaptation of each population to its local environment or simply from random chance. Unique populations of a species, particularly those found at the edges of a species range, are considered an important component of biodiversity, and conservation biologists often recommend their protection (Thompson et al. 2010). Such populations are sometimes designated as distinct varieties or subspecies, especially when they are morphologically distinct. Furthermore, distinctive alleles from these populations can sometimes be used as markers to determine the geographical origin of individuals collected in the wild (Wasser et al. 2008).

Although most mating occurs within populations, individuals occasionally move from one population to another, resulting in the transfer of new alleles and genetic combinations between populations. This genetic transfer is referred to as **gene flow**. Natural gene flow between populations is sometimes interrupted by human activities, causing a reduction in the genetic variation in each population (Wofford et al. 2005).

Genetic variation also occurs within domesticated plants and animals. In traditional agricultural societies, people preserved new plant forms that were well suited to their needs (Laikie et al. 2010). Through generations of this process of **artificial selection**, varieties of species were developed that were high yielding, reliable, and adapted to local conditions of soil, climate, and crop pests. This process has greatly accelerated in modern agriculture, which makes use of scientific breeding programs that manipulate genetic variation to meet present human needs. Without genetic variation, improvements in agriculture would be more difficult. Advanced techniques of biotechnology enable even more precise use of genetic variation by allowing the transfer of genetic material between unrelated species. Thousands of varieties of crops, such as rice, potatoes, and wheat, have been incorporated into the breeding programs of modern agriculture. Among animals, the huge numbers of breeds of domestic dogs, cats, chickens, cattle, sheep, and pigs are evidence of the ability of artificial selection to alter gene pools for the benefit of people.

Genetic variation is also maintained in specialized collections of species used in scientific research, such as the *Drosophila* fruit fly stocks used in genetic studies; the tiny, fast-growing *Arabidopsis* mustard plants that are used in plant research; and the mice used in physiological and medical research.

Human activities are already causing artificial selection in wild species, as seen by pesticide resistance in many agricultural pests and drug resistance in disease-causing bacteria (Myers and Knoll 2001). Evidence also suggests that the intensive harvesting of fish in the ocean is imposing artificial selection on fish populations; targeting the largest fish in the population, among other negative effects, causes selection to favor individuals that reproduce at an earlier age and smaller size (van Wijk et al. 2013).

Ecosystem Diversity

Ecosystems are diverse, and this diversity is apparent even across a particular landscape. As we climb a mountain, for example, the structure of the vegetation and kinds of plants and animals present gradually change from those found in a tall forest to those found in a low, moss-filled forest to alpine meadow to cold, barren rock. As we move across the landscape, physical conditions (soil, temperature,

precipitation, and so forth) change, and one by one the species present at the original location drop out, and we encounter new species that were not found at the starting point. The landscape as a whole is dynamic and changes in response to the overall environment and the types of human activities that are associated with it.

What are communities and ecosystems?

A **biological community** is defined as the species that occupy a particular locality and the interactions among those species. A biological community, together with its associated physical and chemical environment, is termed an **ecosystem**. Many characteristics of an ecosystem result from ongoing processes, including water cycles, nutrient cycles, and energy capture. Water evaporates from leaves, the ground, and other surfaces, to fall again elsewhere as rain or snow and replenish terrestrial and aquatic environments. Soil is built up from parent rock material and decaying organic matter. Photosynthetic plants absorb light energy, which fuels the plants' growth. This energy may be captured by animals that eat the plants, and it may be released as heat when the plants (or the animals that eat them) die and decompose. Plants absorb carbon dioxide and release oxygen during photosynthesis, while animals and fungi absorb oxygen and release carbon dioxide during respiration. Mineral nutrients, such as nitrogen and phosphorus, cycle between the living and the nonliving compartments of the ecosystem. These processes occur at geographical scales that range from square meters to hectares to square kilometers and all the way to regional scales involving tens of thousands of square kilometers (see Table 1.1 for definitions of these metric terms).

The physical environment, especially annual cycles of temperature and precipitation and the characteristics of the land surface, affects the structure and characteristics of a biological community and profoundly influences whether a site will support a forest, grassland, desert, or wetland. In aquatic ecosystems, physical characteristics such as water turbulence and clarity, as well as water chemistry, temperature, and depth, affect the characteristics of the associated **biota** (a region's flora and fauna). In turn, the biological community can also alter the physical characteristics of an environment. For example, wind speeds are lower and humidity is higher inside a forest than in a nearby grassland. Marine communities such as kelp forests and coral reefs (**Box 2.2**) can affect the physical environment as well, by buffering wave action.

Within a biological community, species play different roles and differ in what they require to survive (Marquard et al. 2009). For example, a given plant species might grow best in one type of soil under certain conditions of sunlight and moisture, be pollinated only by certain types of insects, and have its seeds dispersed by certain bird species. Similarly, animal species differ in their requirements, such as the types of food they eat and the types of resting places they prefer (**Figure 2.10**). Even though a forest may be full of vigorously growing green plants, an insect species that feeds only on one rare and declining plant species may be unable to develop and reproduce because it cannot get the specific food that it requires. Any of these requirements may become a **limiting resource** when it restricts population size of the species. For example, a bat species with specialized roosting requirements—forming colonies only in small grottoes on the ceilings of limestone caves—will be restricted by the number of caves with the proper conditions for roosting sites. If people damage the caves to collect limestone, then the bat population will likely decline; however, if the bats are able to adapt to human presence and roost under bridges, their population might remain stable or even increase.

Within a community, each species has its own requirements for food, temperature, water, and other resources, any of which may limit its population size and distribution.

In many ecosystems, there may be occasional episodes of extreme environmental conditions when one or several resources become limited and vulnerable species

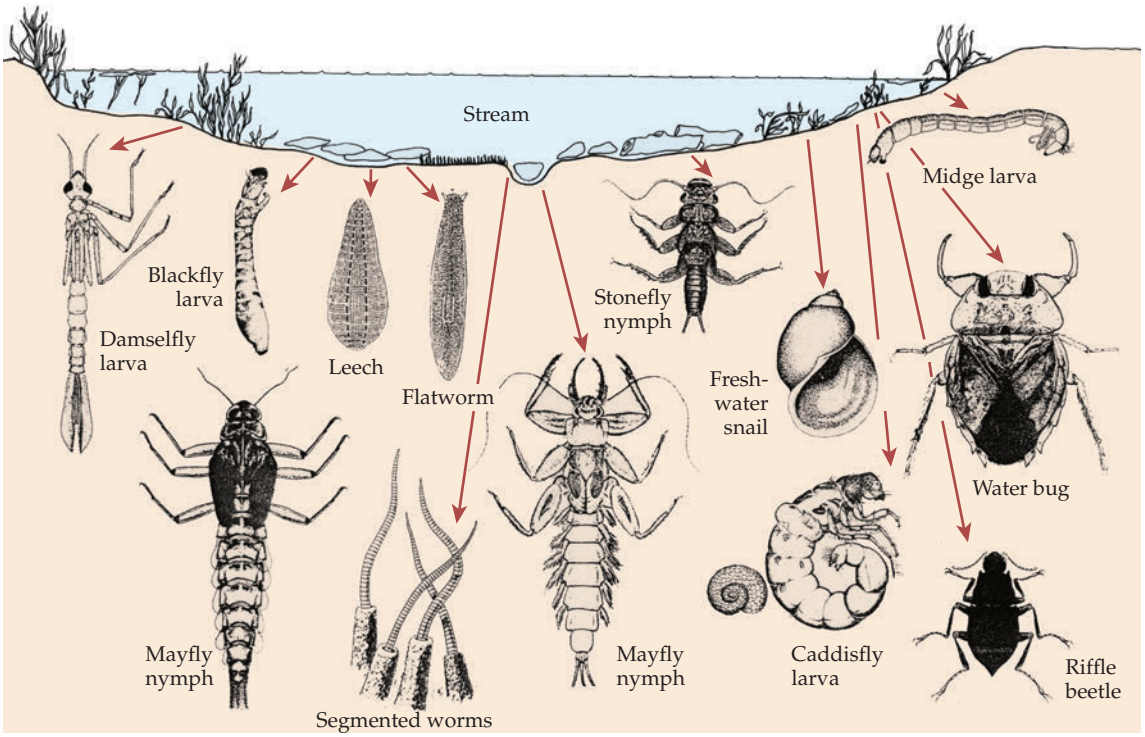


Figure 2.10 In this illustration of a stream community cross section in the Andean mountains, each animal species lives at different water depths and in association with certain structural features of rocks, plants, and sediment. (From Roldán 1988.)

are eliminated from the site. For example, although water is not normally a limiting resource to organisms living in a rain forest, episodes of drought lasting for weeks and even months occasionally do occur, even in the wettest forests. At these times, animal and plant species that need a constant supply of water may vanish. Or, bird species that are specialized to feed on flying insects may be unable to eat or to feed their young during days or weeks when unusually cold, wet, or windy weather prevents insects from flying; in this situation, the flying insects suddenly become the limiting resource for the bird population. Unfortunately, such episodes of extreme conditions are predicted to become more common in coming decades because of global climate change (see Chapter 9). For example, in the Arctic, summer sea ice is declining in abundance due to warming conditions, changing the distribution of numerous animal species and their ecological interactions (Post et al. 2013).

Ecological succession

As a result of its particular requirements, behaviors, or preferences, a given species often ends up appearing in a given site at a particular time during the process of ecological succession (Swanson et al. 2011). **Succession** is the gradual process of change over time in species composition, community structure, soil chemistry, and microclimatic characteristics that occurs following natural and human-caused disturbance in an ecosystem. For example, sun-loving butterflies and annual plants most commonly are found early in succession, in the months or few years immediately following a hurricane or after a logging operation has destroyed an old-growth forest. At this time, with the tree canopy disrupted, the ground is receiving high levels of sunlight, with high temperatures and low humidity during the day. Over the course of decades, the forest canopy is gradually reestablished. Different species, including shade-tolerant, moisture-requiring wildflowers, butterflies