

Chapter 7

LEARNING OBJECTIVES

Biological diversity has become one of the “hot-button” environmental topics — there is a lot of news about endangered species, loss of biodiversity, and its causes. This chapter provides a basic scientific introduction that will help you understand the background to this news, the causes of and solutions to species loss.

Interest in the variety of life on Earth is not new; people have long wondered how the amazing diversity of living things on Earth came to be. This diversity has developed through biological evolution and is affected by interactions among species and by the environment. After reading this chapter, you should understand:

- How mutation, natural selection, migration, and genetic drift lead to evolution of new species.
- Why people value biological diversity.
- How people affect biological diversity: by eliminating, reducing, or altering habitats; harvesting; introducing new species where they had not lived before; and polluting the environment.
- When and how biological diversity is important to ecosystems — how it may affect biological production, energy flow, chemical cycling, and other ecosystem processes.
- What major environmental problems are associated with biological diversity.
- Why so many species have been able to evolve and persist.
- The concepts of the ecological niche and habitat.

Biological Diversity



Wolf calls are one of the sounds of the wilderness, which some fear and some love because it brings them into contact with nature.

Wolves Removed from the Endangered Species Act — Success or Failure in the Conservation of an Endangered Species?

On February 21, 2008, the U.S. federal government took the gray wolf off the endangered species list. Usually, this means that a species has recovered and is no longer in danger of extinction, and is a cause of celebration among conservationists. But this action raised concerns rather than celebration among conservation organizations. Rodger Schlickeisen, president of Defenders of Wildlife, said that current plans “seem designed to lead only to the dramatic decline and need for quick relisting of the wolf. That’s not in anyone’s best interest.” That’s because once delisted, wolves can be hunted.

On March 28, 2008, the delisting of wolves took effect. Within three days, three wolves had been shot and killed. And by May 3, 12 had been killed. Wolves are shot when they are believed to be harassing or harming domestic livestock, or as trophy animals. In Wyoming, as predators, wolves can be killed at any time by any method. “There has been a lot of excitement and interest for hunters in Sublette County,” said Cat Urbigkit, a member of the Sublette County Wyoming Predator Board, meaning that sport hunters were seeking wolves as trophies. Meanwhile, a group of 12 environmental organizations are planning to sue the federal government, arguing that the wolf population is still too small to be considered safe from a second round of regional extinction. Currently there are about 5,200 wolves in the lower 48 states, 1,200 wolves in the Rocky Mountain region and 4,000 in the Great Lakes region. Federal law allows the population to fall to 300 before the federal government can step in again to protect the wolf. Before European settlement of North America, wolves probably numbered in the hundreds of thousands, but it is hard to get a scientifically sound estimate.

Wolves represent a basic conflict in people’s view of nature, wilderness, and biological diversity. To many, wolves are one of the ultimate symbols of true wilderness and their continuation on the Earth has a deep meaning and is of great importance. To others, wolves are dangerous pests, killers of lambs and calves, and ought to be

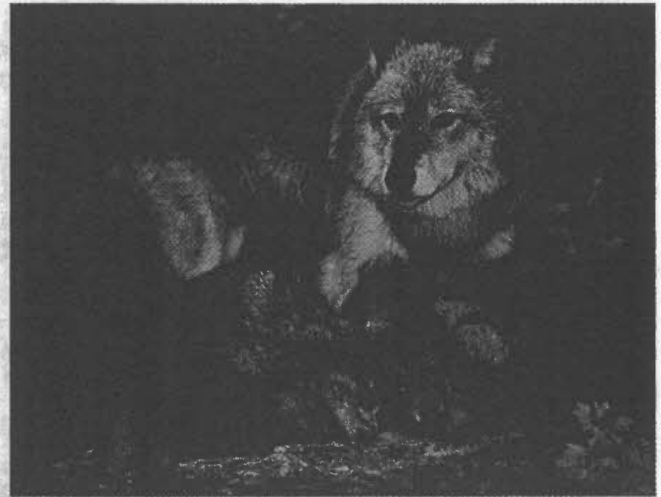


Figure 7.1 ■ Gray wolf of North America.

shot. According to zoologist Susan Crockford, at the University of Victoria, British Columbia, Canada, who is an authority on the evolution of dogs from wolves, “wolves will attack and kill livestock and dogs, and they will kill people under the right conditions,” so people do have a good reason to fear them.

And speaking more generally, people have always loved the great diversity of life and have admired its wonderful animals, including the big predators. But nature also has been something to fear, and wolves somehow bring out that fear in people, as we know from children’s stories and folk stories, like “Peter and the Wolf.”

With this strong duality of feelings about wolves, we confront the basic questions about biological diversity: What does it mean to us, what role does diversity play in sustaining life on Earth, and how can that diversity be conserved? The chapter is an introduction to these issues.¹

7.1 What Is Biological Diversity?

Biological diversity refers to the variety of life-forms, commonly expressed as the number of species in an area, or the number of genetic types in an area. The conservation of biological diversity gets lots of attention these days. One day we hear about polar bears on the news, the next day something about wolves or salmon or elephants or whales. What should we do to protect these species that mean so much to people? What do we need to do about biological diversity in general — all the life-forms, whether people enjoy them or not?

And is this a scientific issue or not? Or is it even partially scientific? That's what this chapter is about. It introduces the scientific concepts concerning biological diversity, explains the aspects of biological diversity that have a scientific base, distinguishes the scientific aspects from the nonscientific ones, and thereby provides a basis for you to evaluate the biodiversity issues you read about.

Why Do People Value Nature? The Eight Reasons

Before we discuss the scientific basis of biodiversity, and the role of science in its conservation, it is necessary to consider why people value biological diversity. There are eight reasons that people value biological diversity: utilitarian; public service; moral; theological; aesthetic; recreational; spiritual; and creative.

Utilitarian means that a species or group of species provides a product that is of direct value to people. Public service means that nature and its diversity provide some service, such as the taking up of carbon dioxide or the pollination of flowers by bees, birds, and bats, that is essential or valuable to human life and would be expensive or impossible to replace by direct human action. Public service also refers to the idea that species have roles in their ecosystems, and that some of these are necessary for the persistence of their ecosystems, perhaps for the persistence of all life. Scientific research tells us which species have such ecosystem roles. Moral means the belief that species have a right to exist, independent of their value to people. Theological means that some religions value nature and its diversity directly, and a person who subscribes to that religion supports this belief.

Aesthetic, recreational, spiritual, and creative have to do with the nonmaterial ways that nature and its diversity benefit people. These are often lumped together, but we separate them here.

Aesthetic refers to the beauty of nature, including the variety of life. Recreational is what it seems — that people enjoy getting out into nature not just because it is beautiful to look at, but because it provides us with activities that we enjoy and that are healthy. Spiritual refers to the way that contact with nature and its diversity has moved

people ever since nature and its diversity have been written about, an uplifting often perceived as a religious experience. Creative refers to the fact that artists, writers, and musicians find stimulation for their creativity from nature and its diversity.

Science helps us directly in determining what are utilitarian and public service functions of biological diversity. Scientific research can lead to discoveries that provide new utilitarian benefits from biological diversity. For example, medical research led to the development of chemotherapy to treat cancer. Taxol, a chemical found in western cedar, was discovered to have chemotherapy properties, which led to harvest of the cedar—an endangered species.

And interestingly, the rise of the scientific and industrial age was accompanied by a great change in the way that people valued nature. For example, before that time, when travel through mountains was difficult, mountains were considered ugly. But around the time of the Romantic poets, travel through the Alps became easier, and suddenly poets began to appreciate the “terrible joy” of mountain scenery. Thus scientific knowledge indirectly influences the nonmaterial ways that people value biological diversity.

The Scientific Basis for Understanding Biodiversity

Discussions about biological diversity are complicated by the fact that people mean various things when they talk about it. They may mean conservation of a single rare species, of a variety of habitats, of the number of genetic varieties, of the number of species, or of the relative abundance of species. These concepts are interrelated, but each has a distinct meaning.

Newspapers and television frequently cover the problem of disappearing species around the world and the need to conserve these species. Before we can intelligently discuss the issues involved in conserving the diversity of life, we must understand how this diversity came to be. This chapter first addresses the principles of biological evolution and then turns to biological diversity itself: its various meanings, how interactions among species increase or decrease diversity, and how the environment affects diversity.

7.2 Biological Evolution

The first big question about biological diversity is: How did it all come about? This is a question people have asked as long as they have written. Before modern science, the diversity of life and the adaptations of living things to their environment seemed too amazing to have come about by chance. The only possible explanation seemed to be that this diversity was created by

God (or gods). People were fascinated by this diversity, and were familiar with it, as illustrated by the famous medieval tapestry *The Hunting of the Unicorn*. In the example shown here (Figure 7.2), a great variety of plants and animals (including frogs and insects) is represented accurately and with great detail. Except for the imaginary unicorn in the center, the tapestry's drawings are familiar to naturalists today. The great Roman philosopher and writer Cicero put it succinctly: "Who cannot wonder at this harmony of things, at this symphony of nature which seems to will the well-being of the world?" He concluded that "everything in the world is marvelously ordered by divine providence and wisdom for the safety and protection of us all."²

With the rise of modern science, however, other explanations became possible. In the nineteenth century, Charles Darwin found an explanation that became known as **biological evolution**. Biological evolution refers to the change in inherited characteristics of a population

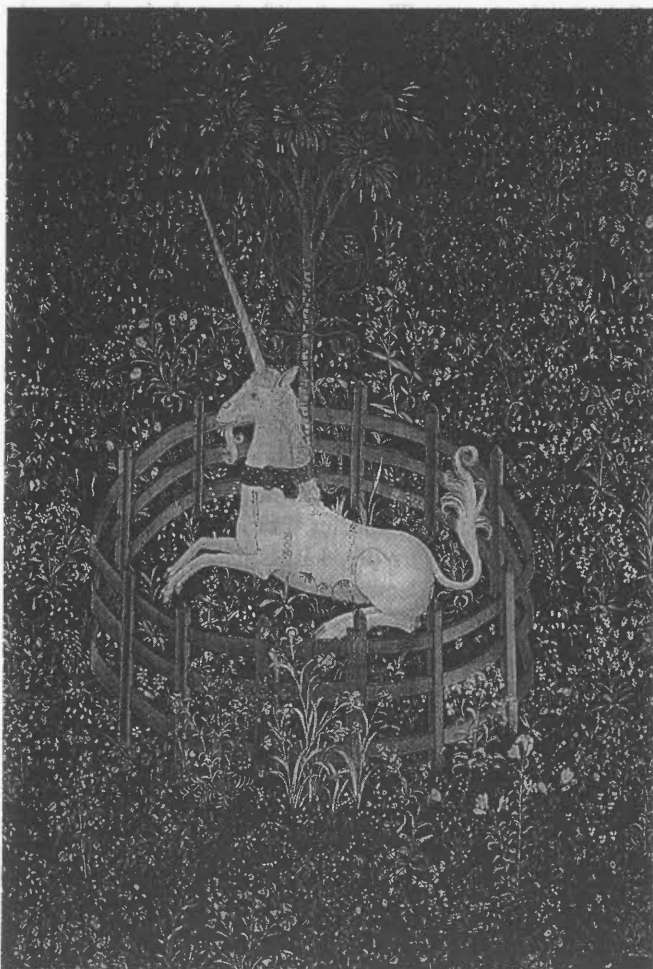


Figure 7.2 ■ People have long loved the diversity of life. Here a Dutch medieval tapestry, *The Hunting of the Unicorn* (late-fifteenth century), celebrates the great diversity of life. Except for the mythological unicorn, all the plants and animals shown are real and drawn with great accuracy.

from generation to generation. It can result in new species—populations that can no longer reproduce with members of the original species. Along with self-reproduction, biological evolution is one of the features that distinguish life from everything else in the universe.

The word *evolution* in the term *biological evolution* has a special meaning. Outside biology, *evolution* is used broadly to mean the history and development of something. For example, book reviewers talk about the evolution of the plot of a novel, meaning how the story unfolds. Geologists talk about the evolution of Earth, which simply means Earth's history and the geologic changes that have occurred over that history. Within biology, however, the term has a more specialized meaning. Biological evolution is a one-way process. Once a species is extinct, it is gone forever. You can run a machine, such as a mechanical grandfather clock, forward and backward. But when a new species evolves, it cannot evolve backward into its parents.

According to the theory of biological evolution, new species arise as a result of competition for resources and the difference among individuals in their adaptations to environmental conditions. Since the environment continually changes, which individuals are best adapted changes too. As Charles Darwin wrote, "Can it be doubted, from the struggle each individual has to obtain subsistence, that any minute variation in structure, habits, or instincts, adapting that individual better to the new [environmental] conditions, would tell upon its vigor and health? In the struggle it would have a better *chance* of surviving; and those of its offspring that inherited the variation, be it ever so slight, would also have a better *chance*." Sounds plausible, but how does this evolution occur? Four processes lead to evolution: mutation, natural selection, migration, and genetic drift.

Mutation

Genes, contained in chromosomes within cells, are inherited—passed from one generation to the next. A *genotype* is the genetic makeup of an individual or group. Genes are made up of a complex chemical compound called deoxyribonucleic acid (DNA). DNA in turn is made up of chemical building blocks that form a code, a kind of alphabet of information. The DNA alphabet consists of four letters (specific nitrogen-containing compounds, called bases), which are combined in pairs: (A) adenine, (C) cytosine, (G) guanine, and (T) thymine. How these letters are combined in long strands determines the "message" interpreted by a cell to produce specific compounds.

Sets of the four base pairs form a **gene**, which is a single piece of genetic information. The number of base pairs that make up a gene varies. To make matters more complex, some base pairs found in DNA are nonfunctional—they are not active and do not determine any chemicals

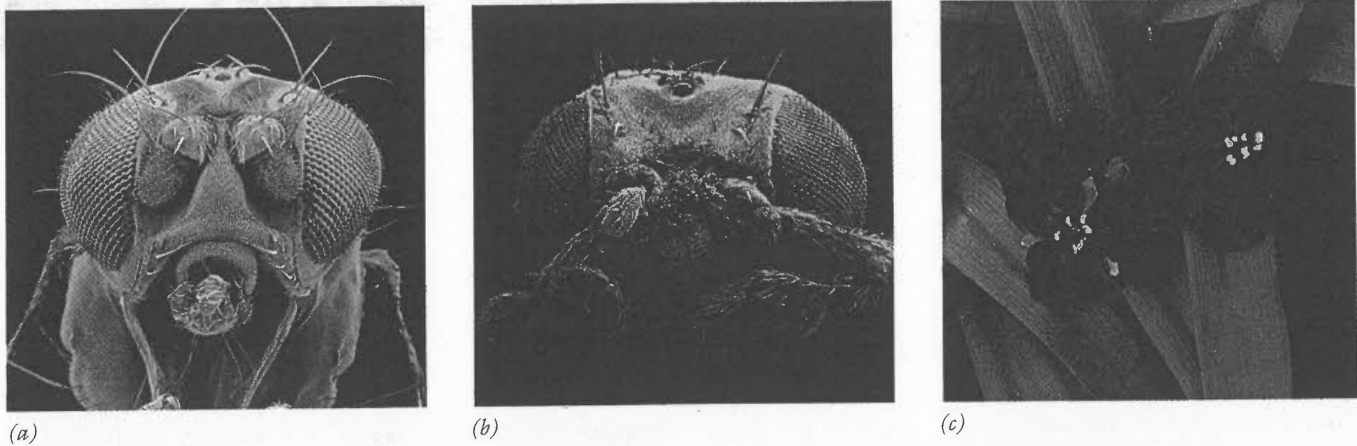


Figure 7.3 ■ A normal fruit fly (*a*), and a fruit fly with an antennae mutation (*b*). *Trandescantia* is a small flowering plant used in the study of effects of mutagens (*c*). The color of stamen hairs in the flower (pink versus clear) is the result of a single gene, and changes when that gene is mutated by radiation or certain chemicals, such as ethylene chloride.

that are produced by the cell. Furthermore, some genes affect the activity of others, turning those other genes on or off. And creatures such as ourselves have genes that limit the number of times a cell can divide—and therefore determine maximum longevity.

When a cell divides, the DNA is reproduced and each new cell gets a copy. Sometimes an error in reproduction changes the DNA and therefore changes inherited characteristics. Sometimes an external agent comes in contact with DNA and alters it. Radiation, such as X rays and gamma rays, can break the DNA apart or change its chemical structure. Certain chemicals also can change DNA. So can viruses. When DNA changes in any of these ways, then it is said to have undergone **mutation**.

In some cases, a cell or offspring with a mutation cannot survive (Figure 7.3*a* and *b*). In other cases, the mutation simply adds variability to the inherited characteristics (Figure 7.3*c*). But in still other cases, individuals with mutations are so different from their parents that they cannot reproduce with normal offspring of their species, so a new species has been created (Figure 7.3).

Natural Selection

When there is variation within a species, some individuals may be better suited to the environment than others. (Change is not always for the better. Mutation can result in a new species whether or not that species is better adapted than its parental species to the environment.) Organisms whose biological characteristics make them better able to survive and reproduce in their environment leave more offspring than others. Their descendants form a larger proportion of the next generation and are more “fit” for the environment. This process of increasing the proportion of offspring is called **natural selection**. Which inherited characteristics lead to more offspring depends on the specific characteristics of an environment, and as the environment changes over time,

the characteristics’ “fit” will also change. In summary, natural selection involves four primary factors:

- Inheritance of traits from one generation to the next and some variation in these traits—that is, genetic variability.
- Environmental variability.
- Differential reproduction that varies with the environment.
- Influence of the environment on survival and reproduction.

Natural selection is illustrated in A Closer Look 7.1, which describes how the mosquitoes that carry malaria develop resistance to DDT and how the microorganism that causes malaria develops a resistance to quinine, a treatment for the disease.

As explained before, when natural selection takes place over a long time, a number of characteristics can change. The accumulation of these changes may be so great that the present generation can no longer reproduce with individuals that have the original DNA structure, resulting in a new species. A **species** is a group of individuals that can (and at least occasionally do) reproduce with each other.

Ironically, the loss of geographic isolation can also lead to a new species. This can happen when one population of a species migrates into a habitat already occupied by another population of that species, thereby changing gene frequency in that habitat. For example, this change in gene frequency can result from the migration of seeds of flowering plants blown by wind or carried in the fur of mammals—if the seed lands in a new habitat, the environment may be different enough to favor genotypes not as favored by natural selection in the parents’ habitat. Natural selection, in combination with geographic isolation and subsequent migration, can thus lead to new dominant genotypes and eventually to new species.



Natural Selection: Mosquitoes and the Malaria Parasite

Malaria poses a great threat to 2.4 billion people—over one-third of the world's population—living in more than 90 countries, most of them located in the tropics. In the United States, Florida has recently experienced a small but serious malaria outbreak. Worldwide, an estimated 300 to 400 million people are infected each year, 1.1 million of whom die.³ In Africa alone, more than 3,000 children die daily from this disease.⁴ It is the fourth largest cause of death in children in developing nations. Once thought to be caused by filth or bad air (hence the name *malaria*, from the Latin for “bad air”), malaria is actually caused by parasitic microbes (four species of the protozoan *Plasmodium*). These microbes affect and are carried by *Anopheles* mosquitoes, which then transfer the protozoa to people. One solution to the malaria problem, then, would be the eradication of *Anopheles* mosquitoes.

By the end of World War II, scientists had discovered that the pesticide DDT was extremely effective against *Anopheles* mosquitoes. They had also found chloroquine highly effective in killing *Plasmodium* parasites. (Chloroquine is an artificial derivative of quinine, a chemical from the bark of the quinine tree that was an early treatment for malaria.)

In 1957 the World Health Organization (WHO) began a \$6 billion campaign to rid the world of malaria using a combination of DDT and chloroquine. At first, the strategy seemed successful. By the mid-1960s, malaria was nearly gone or had been eliminated from 80% of the target areas. However, success

was short-lived. The mosquitoes began to develop a resistance to DDT, and the protozoa became resistant to chloroquine. In many tropical areas, the incidence of malaria worsened. For example, as a result of the WHO program, the number of cases in Sri Lanka had dropped from 1 million to only 17 by 1963. But by 1975, 600,000 cases had been reported, and the actual number is believed to be four times higher. And now there are 500 million cases of malaria resulting in 1 million deaths a year. Resistance among the mosquitoes to DDT became widespread, and resistance of the protozoa to chloroquine was found in 80% of the 92 countries where malaria was a major killer.^{3,5}

The mosquitoes and the protozoa developed this resistance through natural selection. When they were exposed to DDT and chloroquine, the susceptible individuals died. The most resistant organisms survived and passed their resistant genes to their offspring. Since the susceptible individuals died, they left few or no offspring, and any offspring they left were susceptible. Thus, a change in the environment—the human introduction of DDT and chloroquine—caused a particular genotype to become dominant in the populations.

A practical lesson from this experience is that if we set out to eliminate a disease-causing species, we must attack it completely at the outset and destroy all the individuals before natural selection leads to resistance. But sometimes this may be an impossible task, in part because of the natural genetic variation in the target species. Since the drug chloroquine is gener-

ally ineffective now, new drugs have been developed to prevent malaria. However, these second- and third-line drugs will eventually become unsuccessful, too, as a result of the same process of biological evolution by natural selection. This process is speeded up by the ability of the *Plasmodium* to rapidly mutate. In South Africa, for example, the protozoa became resistant to mefloquine immediately after the drug became available as a treatment. An alternative is to develop a vaccine against the *Plasmodium* protozoa.

Biotechnology has made it possible to map the structure of these malaria-causing organisms. Scientists are currently mapping the genetic structure of *P. falciparum*, the most deadly of the protozoa, and expect to finish within several years. With this information, they expect to create a vaccine containing a variety of the species that is benign in human beings but produces an immune reaction.⁶ In addition, scientists are mapping the genetic structure of *Anopheles gambiae*, the carrier mosquito. This project could provide insight into genes, which could prevent development of the malaria parasite within the mosquito. In addition, it could identify genes associated with insecticide resistance and provide clues to developing a new pesticide.⁶

The development of resistance to DDT by mosquitoes and to chloroquine by *Plasmodium* is an example of biological evolution in action today. With the aid of biotechnology, scientists are working to understand the specific chemical structure of the inheritance of characteristics.

Migration and Geographic Isolation

Sometimes two populations of the same species become geographically isolated from each other for a long time. During that time, the two populations may change so much that they can no longer reproduce together even when they are brought back into

contact. In this case, two new species have evolved from the original species. This can happen even if the genetic changes are not more fit but simply different enough to prevent reproduction. **Migration** has been an important evolutionary process over geologic time (a period long enough for geologic changes to take place).

Darwin's visit to the Galápagos Islands gave him his most powerful insight into biological evolution.⁷ There he found many species of finches that were related to a single species found elsewhere. On the Galápagos, each species was adapted to a different niche.⁸ Darwin suggested that finches isolated from other species on the continents eventually separated into a number of groups, each adapted to a more specialized role. This process is called **adaptive radiation**.

More recently and more accessible to most visitors, we can find adaptive radiation on the Hawaiian Islands, where a finchlike ancestor evolved into several species, including fruit and seed eaters, insect eaters, and nectar eaters, each with a beak adapted for its specific food (Figure 7.4).⁹ We can make several generalizations about species diversity on islands, such as the following.

Genetic Drift

Genetic drift occurs when changes in the frequency of a gene in a population are due not to mutation, selection, or migration, but simply to chance. One way this

happens is through the **founder effect**. The founder effect occurs when a small number of individuals are isolated from a larger population; they may have a much smaller genetic variation than the original species (and usually do), and which characteristic the isolated population has will be affected by chance. In both the founder effect and genetic drift, the individuals may not be better adapted to the environment; in fact, they may be more poorly adapted or neutrally adapted. Genetic drift can occur in any small population and may also present problems when a small group is by chance isolated from the main population.

For example, bighorn sheep live in the mountains of the southwestern deserts of the United States and Mexico. In the summer, these sheep feed high up in the mountains, where it is cooler and wetter and there is more vegetation. Before high-density European settlement of the region, the sheep could move freely and sometimes migrated from one mountain to another by descending into the valleys and crossing them in the winter. In this way, large numbers of sheep interbred. With the development of cattle ranches and other human activities, many

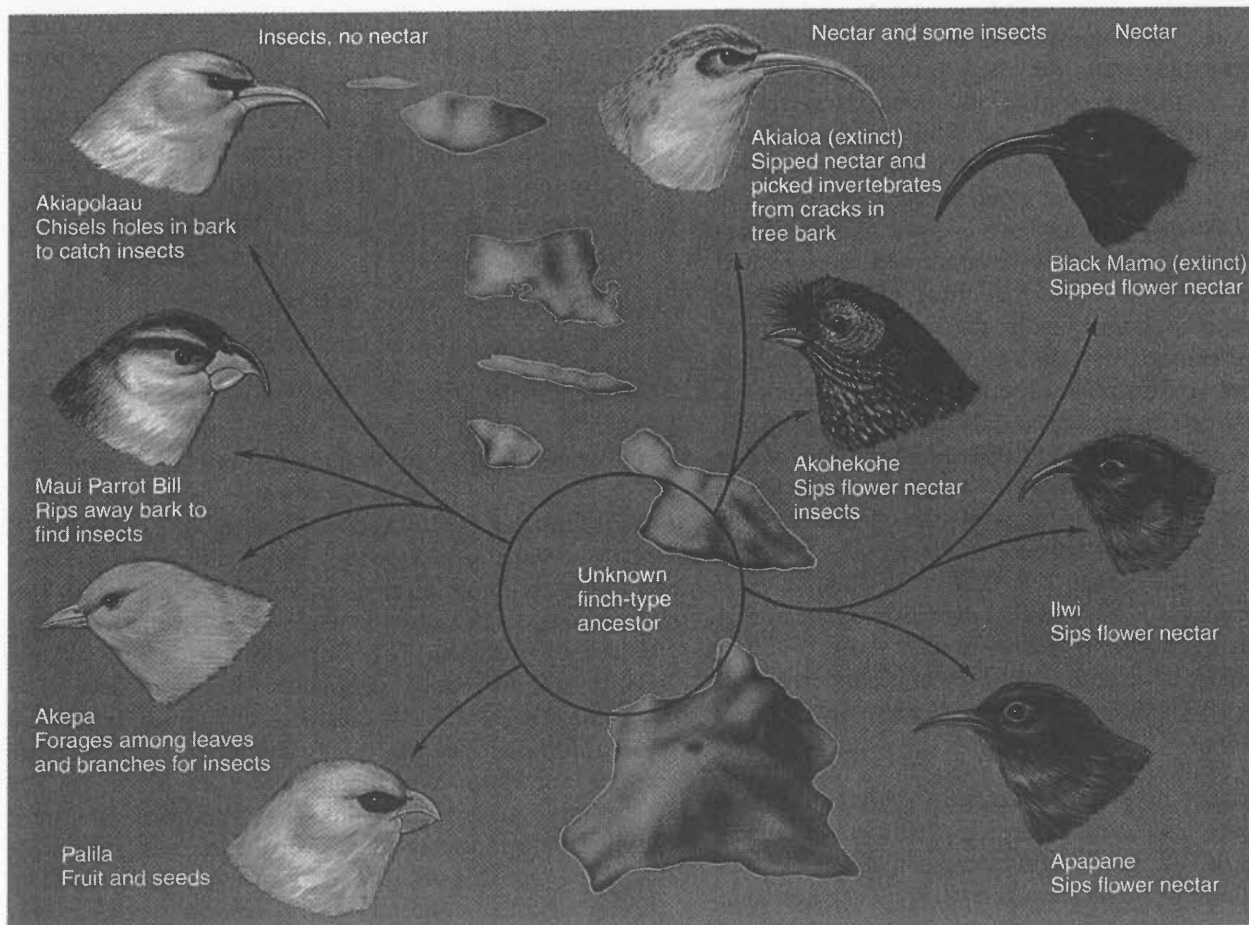


Figure 7.4 ■ Evolutionary divergence among honeycreepers in Hawaii. Sixteen species of birds, each with a beak specialized for its food, evolved from a single ancestor. Nine of the species are shown here. The species evolved to fit ecological niches that, on the North American continent, had previously been filled by other species not closely related to the ancestor. (Source: From C. B. Cox, I. N. Healey, and P. D. Moore, *Biogeography* [New York: Halsted, 1973].)

populations of bighorn sheep could no longer migrate among the mountains by crossing the valleys. These sheep became isolated in very small groups—commonly, a dozen or so—so chance may play a large role in what inherited characteristics remain in the population.

This happened to a population of bighorn sheep on the Tiburon Island in Mexico, which was reduced to 20 animals in 1975, but increased greatly to 650 by 1999. Because of the large recovery, this population of animals has been used to repopulate other bighorn sheep habitats in northern Mexico. But a study of the DNA shows that the genetic variability is much less than in other populations that have been studied in Arizona. Scientists who studied this population suggest that individuals from other isolated bighorn sheep ecological islands should be added to any new transplants, to restore some of the past, greater genetic variation.¹⁰

Biological evolution is so different from other processes that it is worthwhile to spend some extra time exploring the topic. There are no simple rules that species must follow to win or to stay in the game of life. Sometimes when we try to manage species, we assume that evolution will follow simple rules. But species play tricks on us; they adapt or fail to adapt over time in ways that we did not anticipate. Such unexpected outcomes result from our failure to understand fully how species have evolved in relation to their ecological situations. Nevertheless we continue to hope and plan as if life and its environment will follow simple rules. This is true even for the most recent work in genetic engineering. *Complexity is a feature of evolution.* Species have evolved many intricate and amazing adaptations that have allowed them to persist. It is essential to realize that these adaptations have evolved not in isolation but in the context of relationships to other organisms and to the environment. The environment sets up a situation within which evolution, by natural selection, takes place. The great ecologist G. E. Hutchinson referred to this interaction in the title of one of his books, *The Ecological Theater and the Evolutionary Play*. Here, the ecological situation—the condition of the environment and other species—is the scenery and theater within which natural selection occurs, and natural selection results in a story of evolution played out in that theater over the history of life on Earth.¹¹

In summary, what does the theory of biological evolution tell us about biological diversity? Here are some of its implications:

- Since species have evolved and do evolve, and since species are also always becoming extinct, biological diversity is always changing, and which species are present in any one location can change over time.
- Adaptation has no rigid rules; species adapt in response to environmental conditions, and complexity is a natural part of nature. We cannot expect threats to one species to necessarily be threats to another.

- Species and populations do become geographically isolated from time to time, and undergo the founder effect and genetic drift.
- Species are always evolving and adapting to environmental change. One way they get into trouble — become endangered — is when they do not evolve fast enough to keep up with the environment.

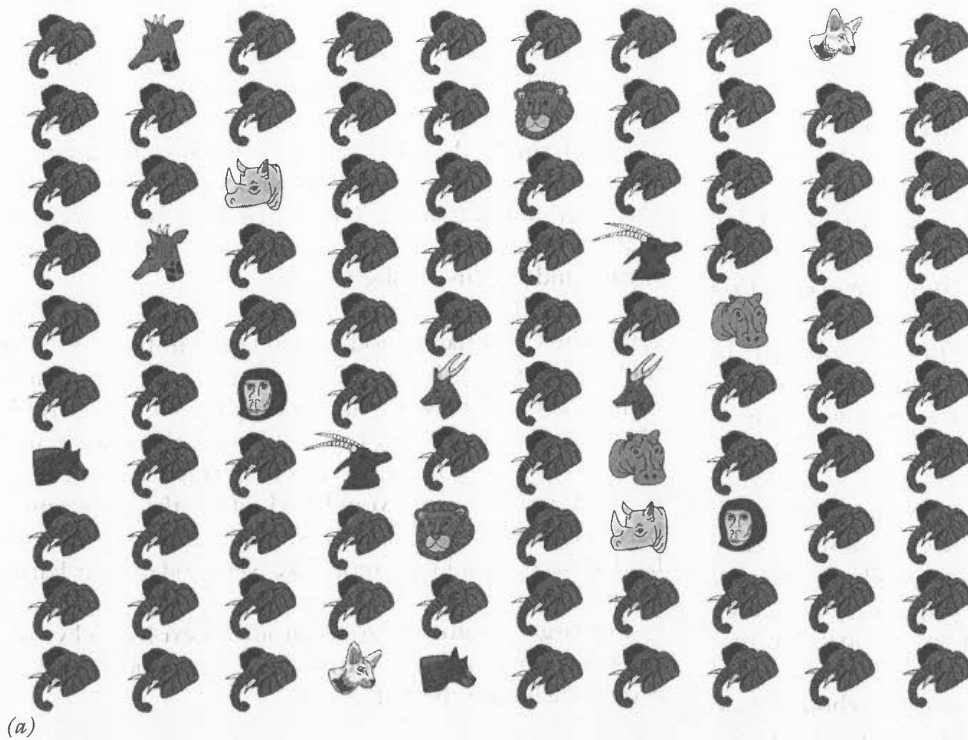
7.3 Basic Concepts of Biological Diversity

Now that we have explained the basic principles of biological evolution, we can turn to biological diversity. The first step in developing workable policies for conserving biological diversity is to be clear about the meaning of the term. This has not always been the case in the past, especially because, as we noted before, biological diversity means different things to different people. Here, in this book, and in environmental science in general, biological diversity involves the following concepts:

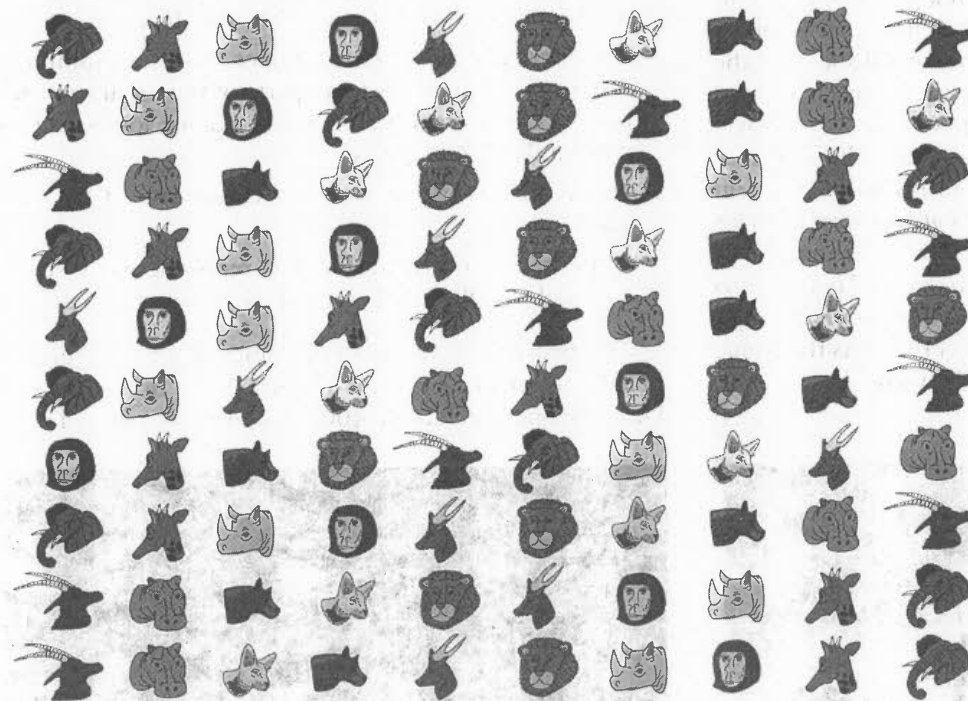
- *Genetic diversity*: the total number of genetic characteristics of a specific species, subspecies, or group of species. In terms of genetic engineering and our new understanding of DNA, this could mean the total base-pair sequences in DNA; the total number of genes, active or not; or the total number of active genes.
- *Habitat diversity*: the different kinds of habitats in a given unit area.
- *Species diversity*, which, in turn, has three qualities:
 - species richness*—the total number of species;
 - species evenness*—the relative abundance of species; and
 - species dominance*—the most abundant species.

To understand the differences among species richness, species evenness, and species dominance, imagine two ecological communities, each with 10 species and 100 individuals, as illustrated in Figure 7.5. In the first community (Figure 7.5*a*), 82 individuals belong to a single species, and the remaining nine species are represented by two individuals each. In the second community (Figure 7.5*b*), all the species are equally abundant; each therefore has 10 individuals. Which community is more diverse?

At first, one might think that the two communities have the same species diversity because they have the same number of species. However, if you walked through both communities, the second would appear more diverse. In the first community, most of the time you would see individuals only of the dominant species (in the case shown in Figure 7.5*a*, elephants); you probably would not see many of the other species at all. In



(a)



(b)

Figure 7.5 ■ Diagram illustrating the difference between species evenness, which is the relative abundance of each species, and species richness, which is the total number of species. Figures (a) and (b) have the same number of species but different relative abundances. Lay a ruler across each diagram and count the number of species the edge crosses. Do this several times, and determine how many species are in each diagram, (a) and (b). See text for explanation of results.

the second community, even a casual visitor would see many of the species in a short time. The first community would appear to have relatively little diversity until it was subjected to careful study. You can test the probability of encountering a new species in either community by laying a ruler down in any direction on Figures 7.5a and 7.5b and counting the number of species that it touches.

As this example suggests, merely counting the number of species is not enough to describe biological diversity. Species diversity has to do with the relative chance of seeing species as much as it has to do with the actual number present. Ecologists refer to the total number of species in an area as *species richness*, the relative abundance of species as *species evenness*, and the most abundant species as *dominant*.

7.4 The Evolution of Life on Earth

The next step in developing workable policies to conserve biological diversity is to understand how this diversity has changed in the past over the Earth's history. For the mosquitoes and their malaria parasite (see A Closer Look 7.1), evolution occurred rapidly. In contrast, during most of Earth's history, evolution seems to have proceeded on average much more slowly.

How do we know about the history of evolution? In part from the study of fossils. The earliest known fossils, 3.5 billion years old, are microorganisms that appear to be ancestral forms of bacteria and what some microbiologists now call Archaea (Figure 7.6).¹²

For the next 2 billion years, only such microbial forms lived on Earth. Amazingly, these organisms greatly changed the global environment, especially by altering the chemistry of the atmosphere. A major way this change came about was from photosynthesis, a capability that evolved during those 2 billion years. As with all photosynthetic organisms, these early ones removed carbon dioxide from the atmosphere and released large amounts of oxygen into it (illustrating our ongoing assertion that life has always changed the environment on a global scale). This led to a high concentration of oxygen in the atmosphere (familiar to us today), setting the ecological stage for the evolution of new forms of life. That free oxygen allowed the evolution of respiration, which paved the way for oxygen-breathing organisms, including, eventually, humans.

An important thing we can take away from this ancient period of life on Earth is that the kind of biological diversity that people are most aware of and value — animals and plants especially — did not exist for life's first 2 billion years on Earth. Geologically speaking the kind of diversity people value is a relatively recent evolutionary event. As the comic strip character Pogo and his friends would have put it, this is a mighty sobering thought.



(a)

The earliest fossils of multicellular organisms appear in approximately 600-million-year-old rocks in southern Australia. These had shells, gills, filters, efficient guts, and circulatory systems, and in these ways they were relatively advanced. Among these were jellyfish-like animals, trilobites, mollusks (clams), echinoderms (such as sea urchins), and sea snails. They must have had ancestors that do not appear in known fossils, but in which these organs and systems evolved.

During this first major period of multicellular life, called the Cambrian period, which lasted until about 500 million years ago, living things remained in the oceans. Almost 100 million years later, during the Silurian period, plants evolved to live on land. Although there were animals in the ocean, if you were able to travel back in time to the Cambrian, you would find an Earth that seemed barren and sterile, at least to ordinary human senses. The land surface would look more like Mars today than Earth today.

For larger, multicellular organisms to evolve to live on the land, some major “innovations,” so to speak, had to evolve, including the following:

- Structural support, needed because, while aquatic organisms are buoyed up by the water, on land gravity becomes a real force with which to contend.
- An internal aquatic environment, with a plumbing system giving it access to all parts of the organism and devices for conserving the water against losses to the surrounding atmosphere.
- Means for exchanging gases with air instead of with water.
- A moist environment for the reproductive system, essential for all sexually reproducing organisms.

The first fish to venture onto land, an obscure group called the crossopterygians (Figure 7.7), did so in the Devonian period (about 400 million years ago). These



(b)

Figure 7.6 ■ Earliest known life: stromatolites. (a) Rocks form from 3.5-billion-year-old fossil of a photosynthetic relative of bacteria; (b) Modern formations of the same or similar bacteria in Shark's Bay, Australia. The ancient fossils are a combination of layers of bacteria and non-biological materials. So are the modern formations.

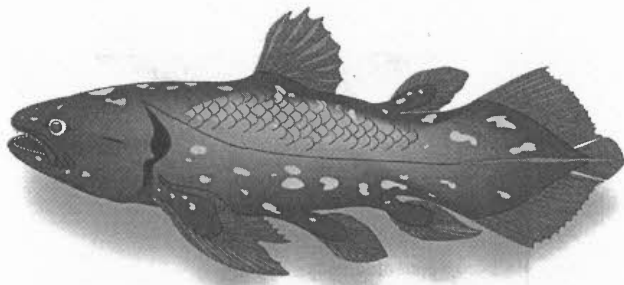


Figure 7.7 ■ Drawing of a crossopterygian, which lived millions of years ago and is the creature that made the transition from sea to land and therefore, in that sense, is the ancestor of all of us. (Source: Ralph E. Taggart, Professor, Department of Plant Biology, Department of Geological Sciences, Michigan State University <http://taggart.glg.msu.edu/isb200/fish.htm>)

gave rise to the amphibians. The crossopterygians had several features that served to make the transition possible. Their lobelike fins, for example, were preadapted as limbs, complete with small bones to form the limb.

They also had internal nostrils characteristic of air-breathing animals. Being fish, the crossopterygians already had a serviceable blood system that was adequate for making a start on land (Figure 7.8). Fossils of amphibians occur even later in the Devonian period about 360

million years ago. Water conservation, however, never became a strong point with amphibians: They retain permeable skins to this day, which is one reason they have never become independent of the aquatic environment.

The earliest land plants were seedless, and the earliest of these could reproduce only in water, so they were limited to wet habitats. These plants reached their peak in dominance of the land in the Carboniferous period (see the appendices at the end of the book for dates for these periods).

Seed plants, the plants that are most familiar and most important to us—those we eat, those that provide shelter, and those that provide much of our landscape beauty—evolved during the Devonian, starting with conifers with naked seeds (plants called *gymnosperms*, which means “naked seed”). The last frontiers for plants—so far, at least—were dry steppes, savannas, and prairies. These were not colonized until grasses evolved, first in the late Cretaceous period (100 million years ago [mya]–65 mya), and occupying large areas in the Tertiary period, about 55 million years ago (Figures 7.9 and 7.10).¹³

Among animals and despite their limitations, amphibians ruled the land for many millions of years during the Devonian period. They had one difficulty that limited their expansion into many niches: They never met the reproductive requirement for life on land.

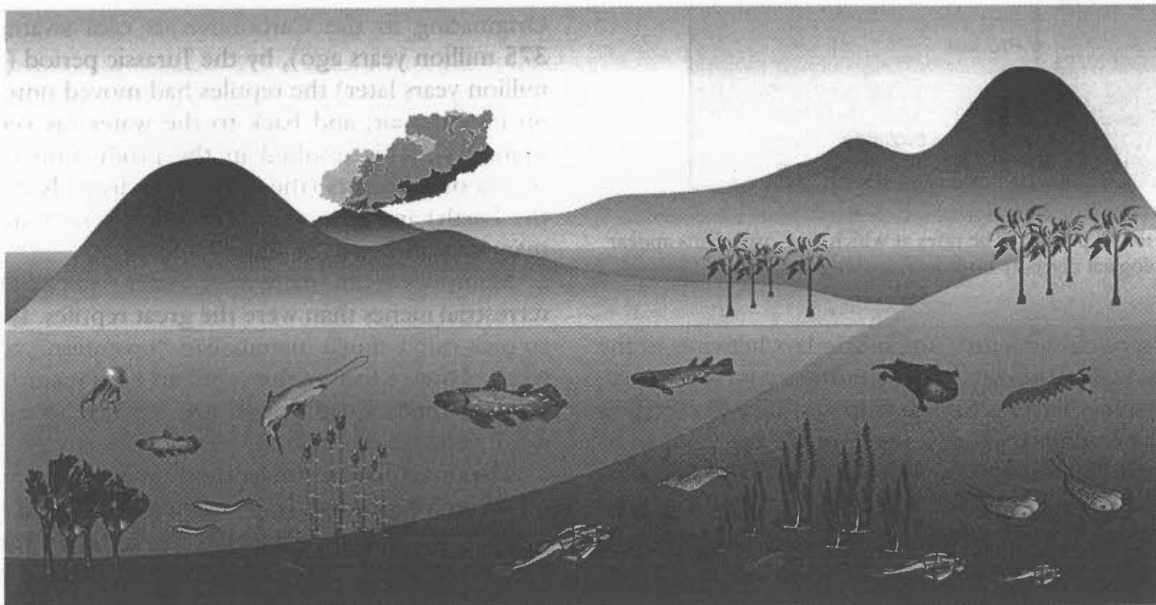


Figure 7.8 ■ When life got onto the land, which happened in the Devonian period (420 to 360 million years before the present [BP]). This illustration shows a reconstruction of a Devonian landscape with animals and plants beginning to occupy the land. For us, it would be a sparse scene with relatively little diversity. On the left is a group of crinoids (animals that were closely related to starfish). These wave in the shallow water currents. Near them are corals and brachiopods (ancient animals that look like, but are not closely related to, clams). Several species of armored fish are swimming or resting on the sandy bottom. To the right are two sea scorpions and another ancient fish. (Source: <http://www.palaeos.com/Paleozoic/Devonian/Devonian.htmgraphic> © from Naturmuseum Senckenberg [Centre for Biodiversity Research]).

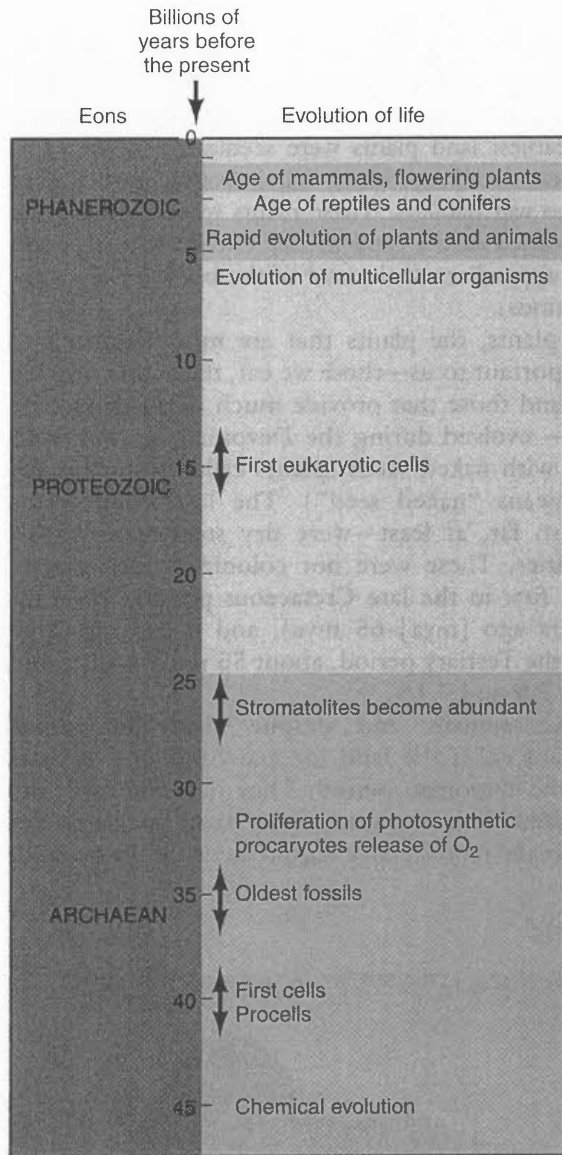


Figure 7.9 ■ The evolution of life on Earth from 4.6 billion years ago to the present. The rates at which new organisms appear and of biological diversity both increase with time.

In most species, the female amphibian lays her eggs in the water, the male fertilizes them there after a courtship ritual, and the young hatch as fishlike tadpoles. Like the seedless plants, the amphibians—with one foot on the land, so to speak—have remained tied to the water for breeding. Some became quite large (2–3 yards long). One branch evolved to become reptiles; the rest that survive are frogs, toads, newts, salamanders, and limbless water “snakes” that seem to have decided that, after all, they prefer a fish’s life.

The reptiles freed themselves from the water by evolving an egg that could be incubated outside of the water and by getting themselves a watertight skin. These two “inventions” gave them the versatility to occupy terrestrial niches that the amphibians had missed because of their bondage to the water. The egg in a hard shell did for reptilian diversity what jaws did for diversity in fishes.

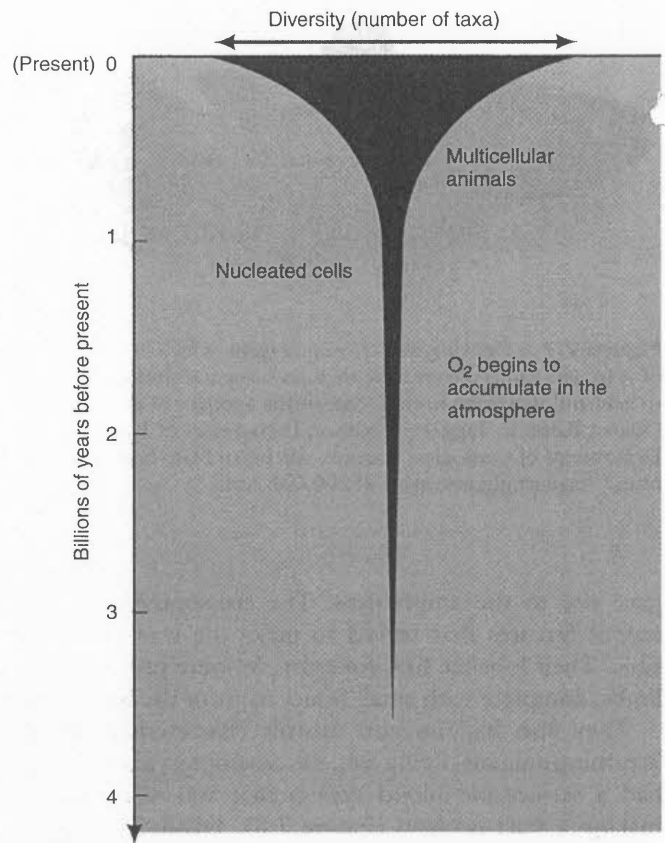


Figure 7.10 ■ A simplified representation of global diversity through geologic time.

Originating in the Carboniferous coal swamps (about 375 million years ago), by the Jurassic period (some 185 million years later) the reptiles had moved onto the land, up into the air, and back to the water (as veritable sea monsters). This resulted in the production of the two orders of dinosaurs (the largest quadrupeds ever to walk the Earth) and gave rise to two new vertebrate classes—mammals and birds (Figure 7.11).

Mammals are in many ways better equipped to occupy terrestrial niches than were the great reptiles. It is difficult to pick out a single mammalian “invention” comparable to the jaws of fish or the reptilian egg; mammals, which are fine-tuned quadrupeds, are adapted to a faster and more versatile life than reptiles.

The mammalian “invention” is perhaps just that: a set of interdependent improvements managed by a more capable brain and supported by a faster metabolism. The placental uterus is sometimes regarded as the key to mammalian success, but it’s really only a piece of equipment mandated by the delicate intricacy of the fetus that lives in it, especially its brain.

Thus life evolved on Earth, bringing us, in the most general way, to the present, where we confront problems about the great diversity of life. The mechanism of biological evolution, the rate at which species evolved and became extinct, and the kinds of environments in which

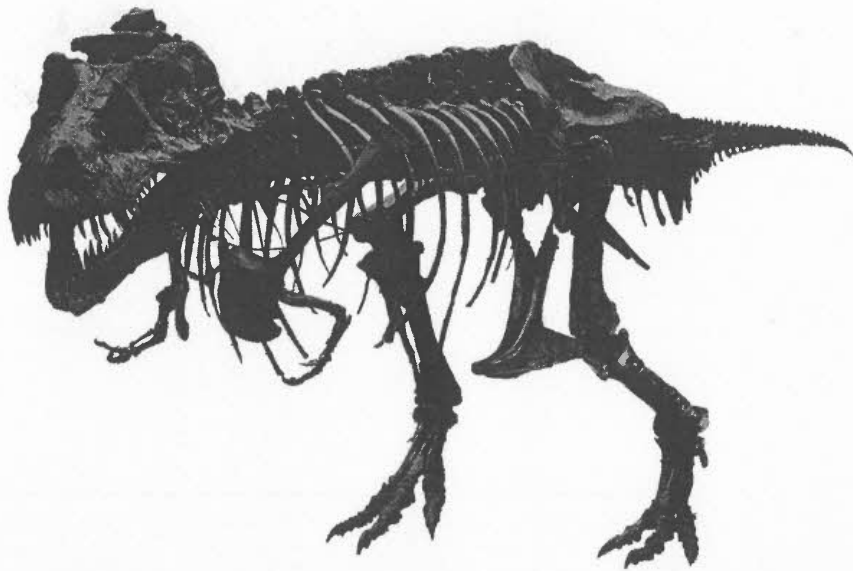


Figure 7.11 ■ (a) T. rex skeleton; (b) Drawing of newly discovered transitional early mammal living during the age of dinosaurs.

species evolve provide essential background to understanding today's biological diversity issues.

During the history of life on Earth, evolution generally proceeded comparatively slowly, as did the extinction of species. But major catastrophes, including the crashing of asteroids onto Earth, rapidly changed the environment at a global level, extinguished many species in a comparatively short time, and opened up niches to which new species then evolved (Figures 7.11 and 7.12).

Environmental change at many scales of time and space is a characteristic of our planet. Species have evolved within this environment and adapted to it. As a result, many species require certain kinds and rates of change. When we slow down or speed up environmental change, we impose novel risks on species.

7.5 The Number of Species on Earth

Many species have come and gone on Earth. But how many exist today? Some 1.5 million species have been named, but biologists estimate that the total number is probably considerably higher, with available estimates suggesting there may be as many as almost 3 million (Table 7.1). And some biologists believe that the number will turn out to be much, much larger. No one knows the exact number because new species are discovered all the time, especially in little-explored areas such as tropical savannas and rain forests.

For example, in the spring of 2008, an expedition sponsored by Conservation International and led by scientists from Brazilian universities discovered 14 new species in or near Serra Geral do Tocantins Ecological Station, a 716,000-hectare protected area in the Cerrado, a remote tropical savanna region of Brazil, said to be one of the areas with the world's greatest biodiversity. They found eight fish, three reptiles, one amphibian, one mammal, and one bird (Figure 7.13).¹⁴

In Laos, five new mammals have been discovered since 1992: (1) the spindle-horned oryx (which is not only a new species but also represents a previously

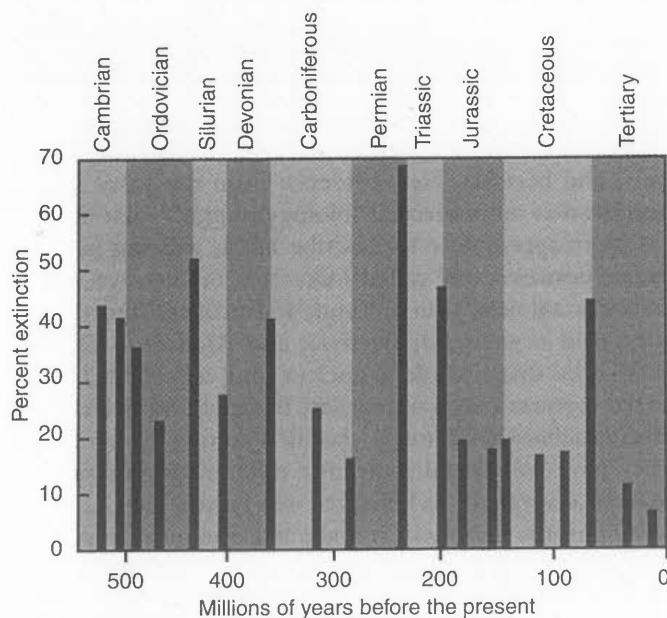


Figure 7.12 ■ A surprising number of great extinction events have occurred during the last 500 million years. The percentage of extinction was determined from the disappearance of genera of well-skeletonized animals.

Table 7.1

Number of Species by Major Form of Life (For a detailed list of species by taxonomic group, see Appendix)

A. Number of Species by Major Forms of Life

Life-Form	Example	Estimated Number	
		Minimum	Maximum
Monera/Bacteria	Bacteria	4,800	10,000
Fungi	Yeast	71,760	116,260
Lichens	Old man's beard	13,500	13,500
Protista/Protoctist	Ameba	80,710	194,760
Plantae	Maple tree	478,365	529,705
Animalia	Honeybee	873,084	1,870,019
Total		1,522,219	2,734,244

B. Number of Animal Species

Animals			
Insecta	Honeybees	668,050	1,060,550
Chondrichthyes	Sharks, rays, etc.	750	850
Osteichthyes	Bony fish	20,000	30,000
Amphibia	Amphibians	200	4,800
Reptilia	Reptiles	5,000	7,000
Aves	Birds	8,600	9,000
Mammalia	Mammals	4,000	5,000
Animal total	Total	873,084	1,870,019

unknown genus); (2) the small black muntjak; (3) the giant muntjak (the muntjak, also known as “barking deer,” is a small deer; the giant muntjak is so called because it has large antlers); (4) the striped hare (whose nearest relative lives in Sumatra); and (5) a new species of civet cat. That such a small country with a long history of human occupancy would have so many new mammal species, and some of these were not all that small, suggests how little we still know about the total

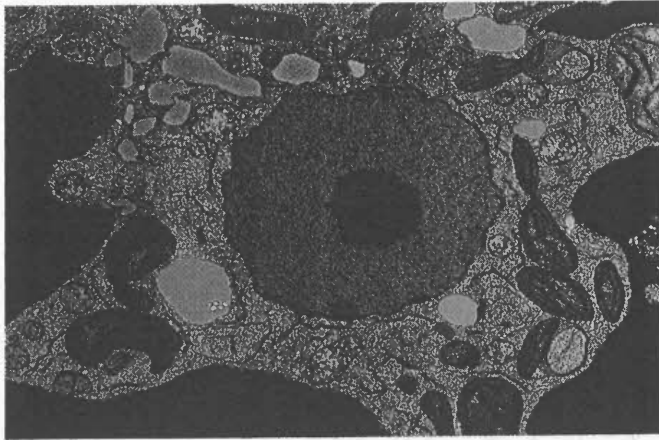


Figure 7.13 ■ A newly discovered species, called the “fat-tailed mouse opossum” (genus *Thylamys*), was one of 14 new species found in Brazil.¹⁴

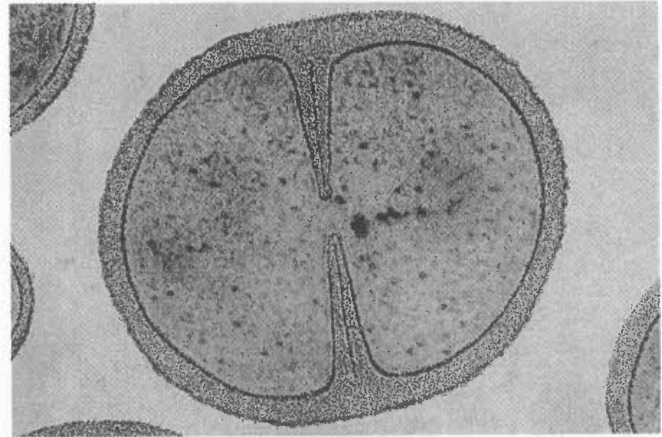
biological diversity on Earth. But as scientists, we must act from what we know, so in this book we will focus our discussions on the 1.5 million species identified and named so far (see Table 7.1).

Many people often think in terms of two major kinds of life: animals and plants. Scientists, however, group living things on the basis of evolutionary relationships—a biological genealogy. In the recent past, scientists classified life into five kingdoms: animals, plants, fungi, protists, and bacteria. New evidence from the fossil record and studies in molecular biology suggest that it may be more appropriate to describe life as existing in three major domains, one called Eukaryota or Eukarya, which includes animals, plants, fungi, and protists (mostly single-celled organisms); Bacteria; and Archaea.¹² Eukarya have cells that include a nucleus and other small organized features called organelles; Bacteria and Archaea do not. (Archaea used to be classified among Bacteria, but they have substantial molecular differences that suggest ancient divergence in heritage—see Figure 7.14.)

Often, the argument is made that the most important thing about biological diversity is the total number of species, and that the primary goal of biological conservation should be to maintain that number at its current known maximum. An interesting and important point to take away from Table 7.1 is that most of the species on Earth are insects (somewhere between 668,000 and more



(a)



(b)

Figure 7.14 ■ Photomicrograph of (a) a eukaryote cell and (b) a bacterial (prokaryote) cell. From these images you can see that the eukaryotic cell has a much more complex structure, including many organelles.

than 1 million) and plants (somewhere between 480,000 and 530,000), and also there are many species of fungi (about 100,000) and protists (about 80,000 to almost 200,000). In contrast, our own kind, the kind of animals that are celebrated most on television and in movies, mammals, number a meager 4,000 to 5,000, about the same as reptiles. When it comes to numbers of species on the Earth, our kind doesn't seem to matter much — about half a percent of all animals. If the total number of species on Earth were the only criterion for what is important, we wouldn't matter.

7.6 Why Are There So Many Species?

Since species compete with one another for resources, and according to the principles of natural selection, the better adapted win out, why wouldn't the losers drop out, leaving only a few winners? For example, we know from our discussions of ecosystems (Chapter 6) that food webs have at least four levels — producers, herbivores, carnivores, and decomposers. Suppose we allow for several more levels of carnivores, so that the average food web had six levels. There are about 20 major kinds of ecosystems (discussed in Chapter 8, "Biogeography"). Then one would guess that the total number of winners on Earth would be only 6×20 or 120 species.

Being a little more realistic, we could take into account adaptations to major differences in climate and other environmental aspects. Perhaps we could specify 100 environmental categories: cold and dry, cold and wet, warm and dry, warm and wet, and so forth. Even so, we would expect that within each environmental category, competitive exclusion would result in the survival of only a few species. Allowing six species per major environmental category would result in only 600 species. That just isn't the

case. How did so many different species survive and how do so many coexist? Part of the answer lies in the different ways in which organisms interact, and part of the answer lies with the idea of the ecological niche.

Interactions between Species

Fundamentally, species interact in three ways: competition, in which the outcome is negative for both groups; symbiosis, which benefits both participants; and predation—parasitism, in which the outcome benefits one and is detrimental to the other. Each type of interaction affects evolution, the persistence of species, and the overall diversity of life.

The Competitive Exclusion Principle

On the side of the debate that there should be only a few species is the **competitive exclusion principle**, which states that *two species that have exactly the same requirements cannot coexist in exactly the same habitat*. Garrett Hardin expressed the idea most succinctly: "Complete competitors cannot coexist."¹⁵

The recent history in Great Britain of the American gray squirrel and the British red squirrel illustrates the competitive exclusion principle (Figure 7.15). The American gray squirrel was introduced into Great Britain because some people thought it was attractive and would be a pleasant addition to the landscape. Thus, its introduction was not accidental but intentional. In fact, about a dozen attempts were made, the first perhaps as early as 1830. By the 1920s, the American gray squirrel was well established in Great Britain, and in the 1940s and 1950s its numbers expanded greatly.

Today, the American gray squirrel is a problem; it competes with the native red squirrel and is winning. The two species have almost exactly the same habitat requirements. At present, there are 2.5 million gray squirrels in Great Britain, and only 140,000 red squirrels, most



(a)



(b)

Figure 7.15 ■ (a) British red squirrel, which is being outcompeted by the introduced (b) American gray squirrel, introduced into Great Britain.

of which are in Scotland, where the gray squirrel is less abundant.¹⁶ Although red squirrels used to be found in deciduous woodlands throughout the lowlands of central and southern Britain, they now are common only in Cambria, Northumberland, and Scotland, with scattered populations in East Anglia, in Wales, on the Isle of Wight, and on islands in Poole Harbor, Dorset.¹⁷ If present trends continue, the red squirrel may disappear from the British mainland in the next 20 years.

One reason for the shift in the balance of these species may be that the main source of food during winter for red squirrels is hazelnuts, while gray squirrels prefer acorns. Thus, red squirrels have a competitive advantage in areas with hazelnuts, and gray squirrels have the advantage in oak forests. When gray squirrels were introduced, oaks were the dominant mature trees in Great Britain; about 40% of the trees planted were oaks.

The introduction of the gray squirrel into Great Britain illustrates *one of the major causes of modern threats to biological diversity: the introduction by people of species into new habitats*. Introduced competitors frequently threaten native species. We will look at this issue again in Chapter 8.

So, according to the competitive exclusion principle, complete competitors cannot coexist; one will always exclude the other. This doesn't sound good for the conservation of a high level of biological diversity. How so many species survive together on the Earth is answered in part by the concept of the ecological niche.

7.7 Niches: How Species Coexist

The niche concept explains how so many species can coexist, and this concept is introduced most easily by experiments done with small, common insects—flour

beetles (*Tribolium*), which, as their name suggests, live on wheat flour. Flour beetles make good experimental subjects because they require only small containers of wheat flour to live and are easy to grow (in fact, too easy; if you don't store your flour at home properly, you will find these little beetles happily eating in it).

The flour beetle experiments work like this: A specified number of beetles of two species are placed in small containers of flour—each container with the same number of beetles of each species. The containers are then maintained at various temperature and moisture levels—some are cool and wet, others warm and dry. Periodically, the beetles in each container are counted. This is very easy. The experimenter just puts the flour through a sieve that lets the flour through but not the beetles. Then the experimenter counts the number of beetles of each species and puts the beetles back in their container to eat, grow, and reproduce for another interval. Eventually, one species always wins—some of its individuals continue to live in the container while the other species goes extinct. So far, it would seem that there should be only one species of *Tribolium*. But which species survives depends on temperature and moisture. One species does better when it is cold and wet, the other when it is warm and dry (Figure 7.16).

Curiously, when conditions are in between, sometimes one species wins and sometimes the other, seemingly randomly; but invariably one persists while the second becomes extinct. So the competitive exclusion principle holds for these beetles. Both species can survive in a complex environment—one that has cold and wet habitats as well as warm and dry habitats. In no location, however, do the species coexist.

The little beetles provide us with the key to the coexistence of many species. Species that require the same resources can coexist by utilizing those resources under different environmental conditions. So it is habitat

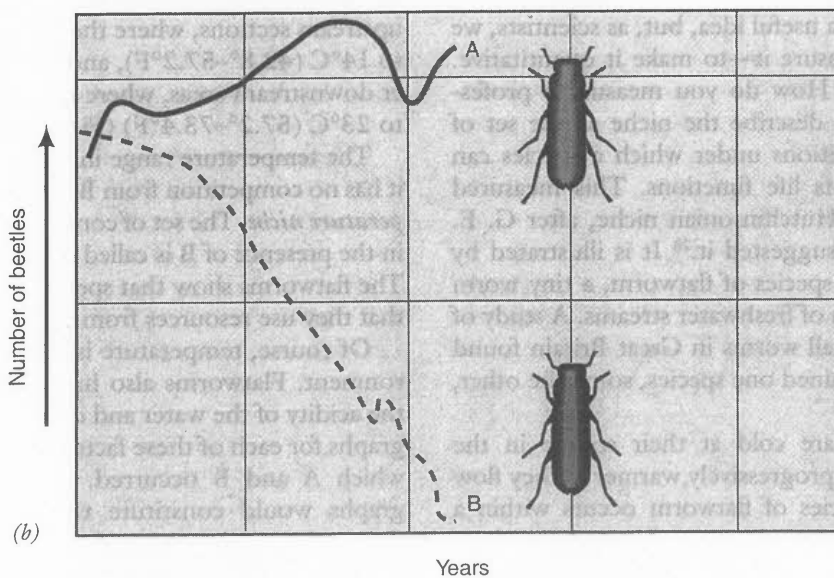
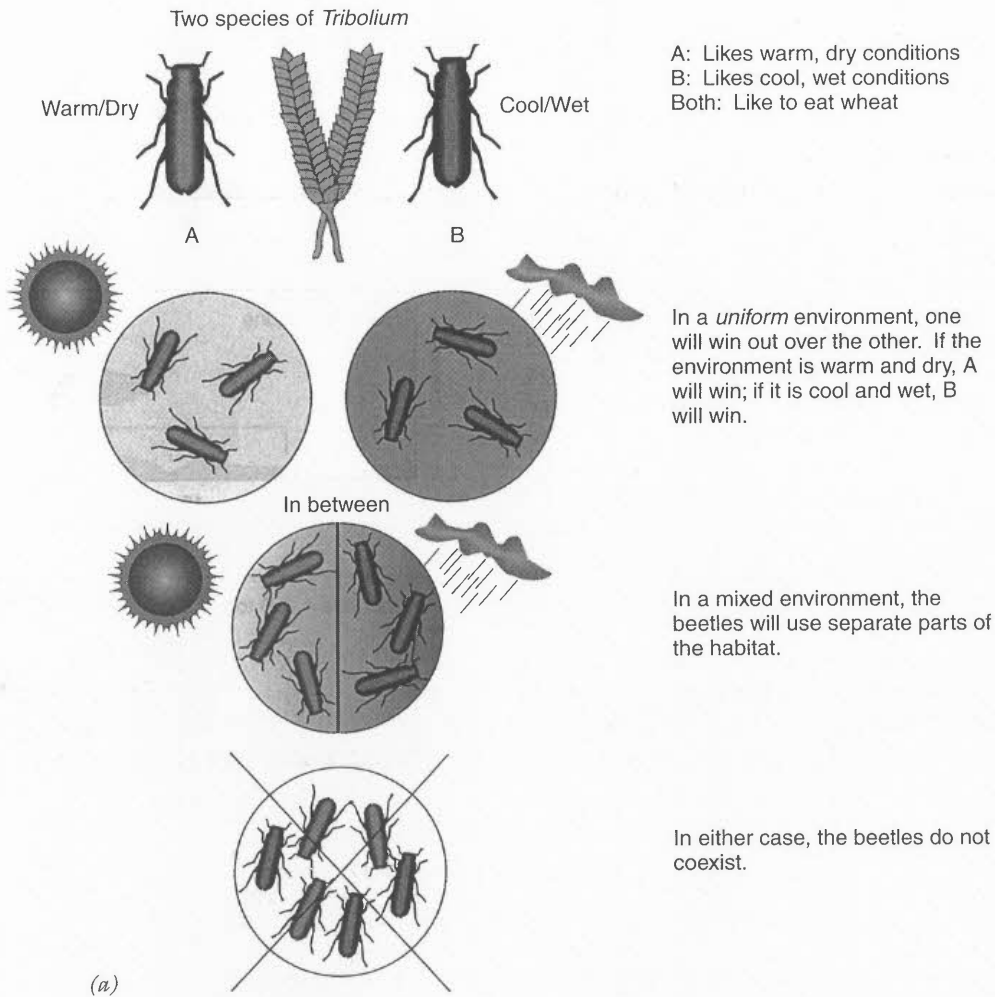


Figure 7.16 ■ A classical experiment with flour beetles. Two species of flour beetles are placed in small containers of flour. Each container is kept at a specified temperature and humidity. Periodically, the flour is sifted and the beetles counted and then returned to their containers. Which species persists is observed and recorded. (a) The general process illustrating competitive exclusion in these species; (b) Results of a specific, typical experiment under warm, dry conditions.

complexity that allows complete competitors—and not-so-complete competitors—to coexist¹⁸ because they avoid competing with each other.

Professions and Places: The Ecological Niche and the Habitat

The flour beetles are said to have the same ecologically functional niche, which means they have the same *profession*—eating flour. But they have different *habitats*. Where a species lives is its *habitat*, but what it does for a living (its profession) is its *ecological niche*.¹⁹ Suppose you have a neighbor who is a bus driver. Where your neighbor lives and works is your town—that's this person's habitat. What your neighbor does is drive a bus—that's this person's niche. Similarly, if someone says, "Here comes a wolf," you think not only of a creature that inhabits the northern forests (its habitat) but also of a predator that feeds on large mammals (its niche).

Understanding the niche of a species is useful in assessing the impact of development or of changes in land use. Will the change remove an essential requirement for some species' niche? A new highway that makes car travel easier might eliminate your neighbor's bus route (an essential part of the habitat) and thereby eliminate this niche. Other things could also eliminate this niche. Suppose a new school were built so that all the children could walk to school. Then a bus driver would not be needed; this niche would no longer exist in your town. In the same way, cutting a forest may drive away prey and eliminate the niche of the wolf.

Measuring Niches

The ecological niche is a useful idea, but, as scientists, we want to be able to measure it—to make it quantitative. How can we do that? How do you measure a profession? One answer is to describe the niche as the set of all environmental conditions under which a species can persist and carry out its life functions. This measured niche is known as the Hutchinsonian niche, after G. E. Hutchinson, who first suggested it.²⁰ It is illustrated by the distribution of two species of flatworm, a tiny worm that lives on the bottom of freshwater streams. A study of two species of these small worms in Great Britain found that some streams contained one species, some the other, and still others both.¹⁸

The stream waters are cold at their source in the mountains and become progressively warmer as they flow downstream. Each species of flatworm occurs within a specific range of water temperatures. In streams where species A occurs alone, it is found from 6° to 17°C (42.8°–62.6°F) (Figure 7.17a). Where species B occurs alone, it is found from 6° to 23°C (42.8°–73.4°F) (Figure 7.17b). When they occur in the same stream, their temperature ranges are much narrower. Species A lives in the

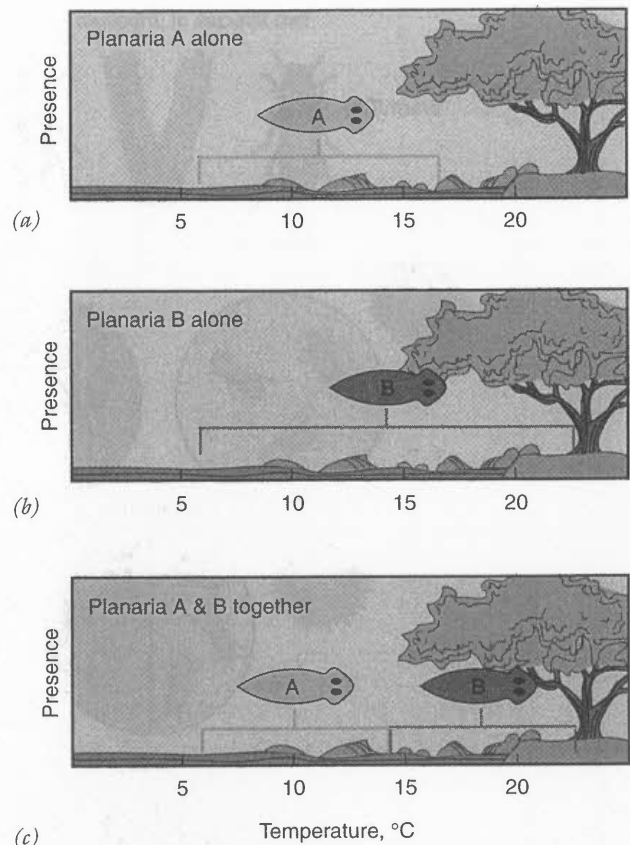


Figure 7.17 ■ The occurrence of freshwater flatworms in cold mountain streams in Great Britain. (a) The presence of species A in relation to temperature in streams where it occurs alone. (b) The presence of species B in relation to temperature in streams where it occurs alone. (c) The temperature range of both species in streams where they occur together. Inspect the three graphs: what is the effect of each species on the other?

upstream sections, where the temperature ranges from 6° to 14°C (42.8°–57.2°F), and species B lives in the warmer downstream areas, where temperatures range from 14° to 23°C (57.2°–73.4°F) (Figure 7.17c).

The temperature range in which species A occurs when it has no competition from B is called its *fundamental temperature niche*. The set of conditions under which it persists in the presence of B is called its *realized temperature niche*. The flatworms show that species divide up their habitat so that they use resources from different parts of it.

Of course, temperature is only one aspect of the environment. Flatworms also have requirements in terms of the acidity of the water and other factors. We could create graphs for each of these factors, showing the range within which A and B occurred. The collection of all those graphs would constitute the complete Hutchinsonian description of the niche of a species.

A Practical Implication

From the discussion of the competitive exclusion principle and the ecological niche, we learn something important about the conservation of species: If we want to conserve

a species in its native habitat, we must make sure that all the requirements of its niche are present. Conservation of endangered species is more than a matter of putting many individuals of that species into an area; all the life requirements for that species must also be present—we have to conserve not only a population, but its habitat and its niche.

Symbiosis

Our discussion up to this point might leave the impression that species interact mainly through competition—by interfering with one another. But **symbiosis** is also important. This term is derived from a Greek word meaning “living together.” In ecology, symbiosis describes *a relationship between two organisms that is beneficial to both and enhances each organism’s chances of persisting*. Each partner in symbiosis is called a **symbiont**.

Symbiosis is widespread and common; most animals and plants have symbiotic relationships with other species. We humans have symbionts — microbiologists tell us that about 10% of a person’s body weight is actually the weight of symbiotic microorganisms in the intestines. The resident bacteria help our digestion; we provide a habitat that supplies all their needs; both we and they benefit. We become aware of this intestinal community when it changes—for example, when we travel to a foreign country and ingest new strains of bacteria. Then we suffer a well-known traveler’s malady, gastrointestinal upset.

Another important kind of symbiotic interaction occurs between certain mammals and bacteria. A reindeer on the northern tundra may appear to be alone but carries with it many companions. Like domestic cattle, the reindeer is a ruminant, with a four-chambered stomach (Figure 7.18) teeming with microbes (a billion per cubic centimeter). In this partially closed environment, the respiration of microorganisms uses up the oxygen ingested by the reindeer while eating. Other microorganisms digest cellulose, take nitrogen from the air in the stomach, and make proteins. The bacterial species that digest the parts of the vegetation that the reindeer cannot digest itself (in particular, the cellulose and lignins of cell walls in woody tissue) require a peculiar environment: They can survive only in an environment without oxygen. One of the few places on Earth’s surface where such an environment exists is the inside of a ruminant’s stomach.²¹ The bacteria and the reindeer are symbionts, each providing what the other needs; and neither could survive without the other. They are therefore called obligate symbionts.

A Broader View of Symbiosis

So far we have discussed symbiosis in terms of physiological relationships between organisms of different species. But symbiosis is much broader, and includes social and behavioral relationships that benefit both populations. Referring back to the opening case history of this chapter,

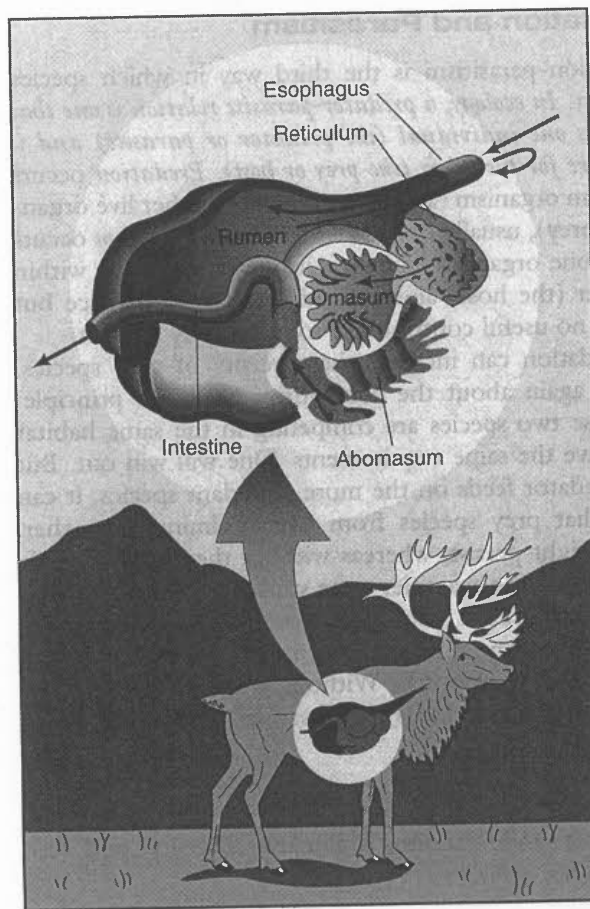


Figure 7.18 ■ The stomach of a reindeer illustrates complex symbiotic relationships. For example, in the rumen, bacteria digest woody tissue the reindeer could not otherwise digest. The result is food for the reindeer and food and a home for the bacteria, which could not survive in the local environment outside.

dogs are much more abundant than wolves. Wolves avoid human beings and have been long feared and disliked by many peoples, but dogs have done very well because of the behavioral connection with people. Being friendly, helpful, and companionable to people has made dogs very abundant. This is another kind of symbiosis.

Crop plants illustrate another kind of symbiosis. Plants depend on animals to spread their seeds and have evolved symbiotic relationships with them. That’s why fruits are so eatable; it’s a way for plants to get their seeds spread, as Henry David Thoreau discussed in his book *Faith in a Seed*.

A Practical Implication

We can see that symbiosis promotes biological diversity and that if we want to save a species from extinction, we must save not only its habitat and niche but also its symbionts. This suggests another important point that will become more and more evident in later chapters: The attempt to save a single species almost invariably leads us to conserve a group of species, not just a single species or a particular physical habitat.

Predation and Parasitism

Predation–parasitism is the third way in which species interact. *In ecology, a predator–parasite relation is one that benefits one individual (the predator or parasite) and is negative for the other (the prey or host).* Predation occurs when an organism (a predator) feeds on other live organisms (prey), usually of another species. Parasitism occurs when one organism (the parasite) lives on, in, or within another (the host) and depends on it for existence but makes no useful contribution to it and may harm it.

Predation can increase the diversity of prey species. Think again about the competitive exclusion principle. Suppose two species are competing in the same habitat and have the same requirements. One will win out. But if a predator feeds on the more abundant species, it can keep that prey species from overwhelming the other. Both might persist, whereas without the predator, only one would. For example, some studies have shown that a moderately grazed pasture has more species of plants than an ungrazed one. The same seems to be true for natural grasslands and savannas. Without grazers and browsers, then, African grasslands and savannas might have fewer species of plants.

A Practical Implication

Predators and parasites influence diversity and can increase it.

7.8 Environmental Factors That Influence Diversity

Species are not uniformly distributed over the Earth's surface; diversity varies greatly from place to place. For instance, suppose you were to go outside and count all the species in a field or any open space near where you are reading this book (that would be a good way to begin to learn for yourself about biodiversity). The number of species you found would depend on where you are. If you live in northern Alaska or Canada, Scandinavia, or Siberia, you would probably find a significantly smaller number of species than if you live in the tropical areas of Brazil, Indonesia, or central Africa. Variation in diversity is partially a question of latitude—in general, greater diversity occurs at lower latitudes. Diversity also varies within local areas. If you count species in the relatively sparse environment of an abandoned city lot, for example, you will find quite a different number than if you counted species in an old, long-undisturbed forest. The large-scale geographic pattern in the distribution of species, called *biogeography*, is the topic of the next chapter. For now, we will look at some of the environmental factors that influence diversity locally. Table 7.2 summarizes several of these factors.

The species and ecosystems that occur on the land change with soil type and topography: slope, aspect (the direction the slope faces), elevation, and nearness to a

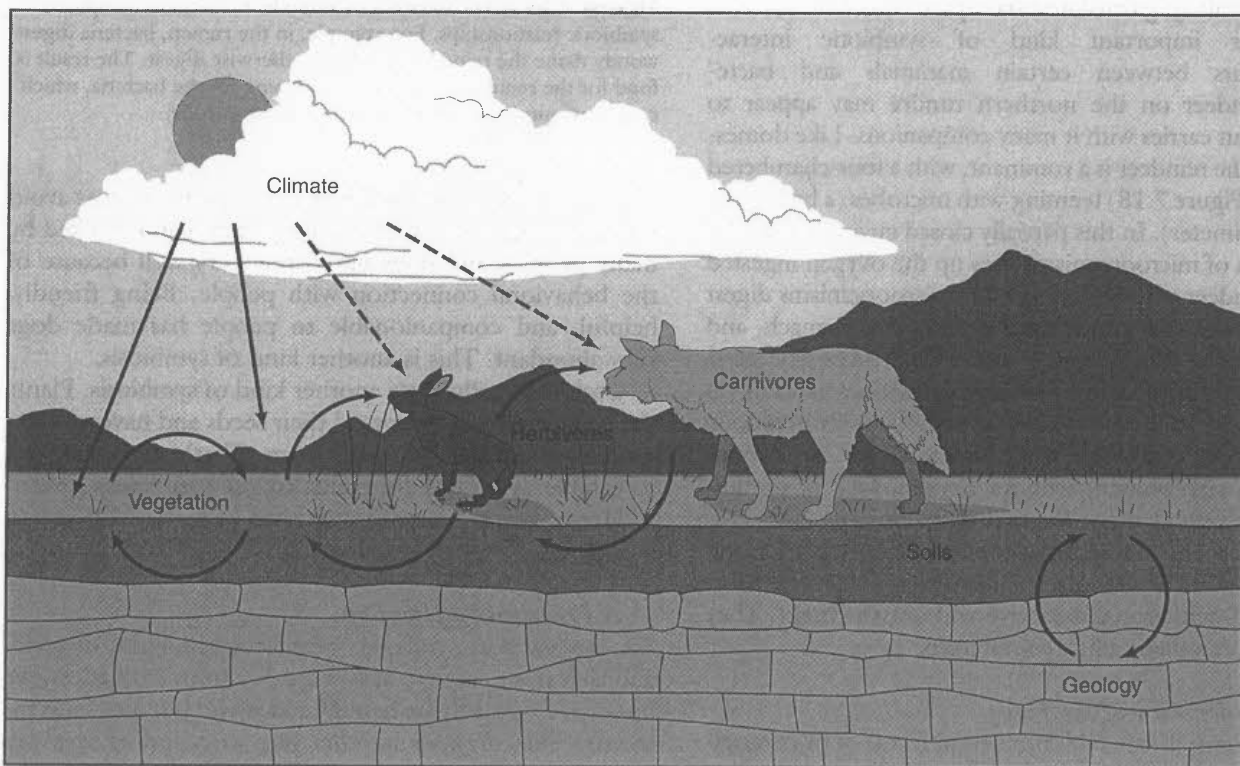


Figure 7.19 ■ Interrelationships among climate, geology, soil, vegetation, and animals. What lives where depends on many factors. Climate, geologic features (bedrock type, topographic features), and soils influence vegetation. Vegetation in turn influences soils and the kinds of animals that will be present. Animals affect the vegetation. Arrows represent a causal relationship; the direction is from cause to effect. A dashed arrow indicates a relatively weak influence, and a solid arrow a relatively strong influence.

Table 7.2 Some Major Factors That Increase and Decrease Biological Diversity

A. Factors that tend to increase diversity

1. A physically diverse habitat.
2. Moderate amounts of disturbance (such as fire or storm in a forest or a sudden flow of water from a storm into a pond).
3. A small variation in environmental conditions (temperature, precipitation, nutrient supply, etc.).
4. High diversity at one trophic level increases the diversity at another trophic level. (Many kinds of trees provide habitats for many kinds of birds and insects.)
5. An environment highly modified by life (e.g., a rich organic soil).
6. Middle stages of succession.
7. Evolution.

B. Factors that tend to decrease diversity

1. Environmental stress.
2. Extreme environments (conditions near the limit of what living things can withstand).
3. A severe limitation in the supply of an essential resource.
4. Extreme amounts of disturbance.
5. Recent introduction of exotic species (species from other areas).
6. Geographic isolation (being on a real or ecological island).

drainage basin. These factors influence the number and kinds of plants. The kinds of plants, in turn, influence the number and kinds of animals. Some of the possible interrelationships are illustrated in Figure 7.19.²²

Such a change in species can be seen with changes in elevation in mountainous areas like those at the Grand Canyon and the nearby San Francisco Mountains of Arizona (Figure 7.20). Although such patterns are most easily seen in vegetation, they occur for all organisms. See, for example, the pattern of distribution of African mammals on Mount Kilimanjaro (Figure 7.21).

Some habitats harbor few species because they are stressful to life, as a comparison of vegetation in two areas of Africa illustrates. In eastern and southern Africa, well-drained, sandy soils support diverse vegetation, including many species of *Acacia* and *Combretum* trees as well as many grasses. In contrast, woodlands on the very heavy clay soils of wet areas near rivers, such as the Sengwa River in Zimbabwe, are composed almost exclusively of a single species called *Mopane*. Very heavy clay soils store water and prevent most oxygen from reaching roots. As a result, only tree species with very shallow roots survive.

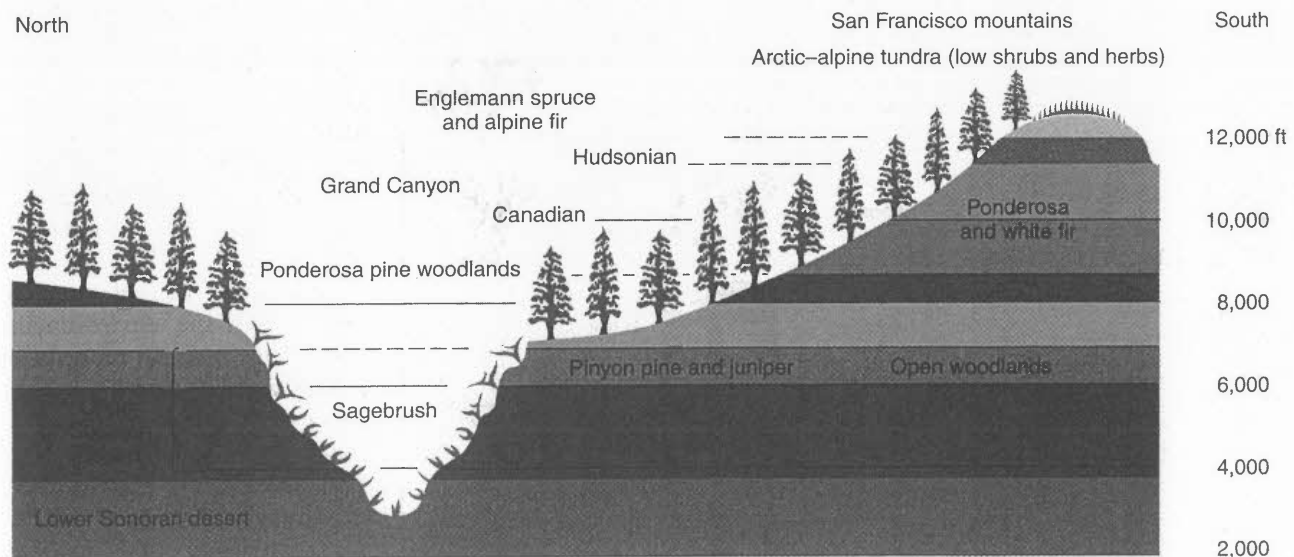


Figure 7.20 ■ Change in the relative abundance of a species over an area or a distance is referred to as an *ecological gradient*. Such a change can be seen with changes in elevation in mountainous areas. The altitudinal zones of vegetation in the Grand Canyon of Arizona and the nearby San Francisco Mountains are shown. (Source: From C. B. Hunt, *Natural Regions of the United States and Canada* [San Francisco: W. H. Freeman, 1974], copyright 1974 by W. H. Freeman.)

Moderate environmental disturbance can also increase diversity. For example, fire is a common disturbance in many forests and grasslands. Occasional light fires produce a mosaic of recently burned and unburned areas. These patches favor different kinds of species and increase overall diversity. Of course, people also affect diversity. In general, urbanization, industrialization, and agriculture decrease diversity, reducing the number of habitats and simplifying habitats. (See, for example, the effects of agriculture on habitats, discussed in Chapter 11.) In addition, we intentionally favor specific species and manipulate populations for our own purposes, as when a person plants a lawn or when a farmer plants a single crop over a large area.

Most people don't think of cities as having any beneficial effects on biological diversity. Indeed, the development of cities tends to reduce biological diversity. This is, in part, because cities have typically been located at good sites for travel, such as along rivers or near oceans, where biological diversity is often high. However, in recent years we have begun to realize that cities can contribute in important ways to the conservation of biological diversity.

7.9 Genetic Engineering and Some New Issues about Biological Diversity

Our understanding of evolution today owes a lot to the modern science of molecular biology and the practice of genetic engineering, which are creating a revolution in how we think about and deal with species. At present, scientists have essentially the complete DNA code for five species: the fruit fly (*Drosophila*); a nematode worm called

C. elegans (a very small worm that lives in water); yeast; a small weed plant, thale cress (*Arabidopsis thaliana*); and ourselves—humans. Scientists focused on these species either because they are of great interest to us (as with ourselves) or because they are relatively easy to study—having either few base pairs (the nematode worm) or having genetic characteristics that were well known (the fruit fly).

Environmental Issues as Information Issues

The amount of information contained in DNA is enormous. Thale cress's DNA consists of 125 million base pairs, and this is comparatively few. Important crop plants have even larger numbers of base pairs. Rice has 430 million and wheat more than 16 billion! The base pairs in thale cress appear to make up approximately 25,000 genes, but many are duplicates; so there are probably about 15,000 unique genes that determine what thale cress will be like. This is about the same number of genes in the nematode worm and the fruit fly. In contrast, the number of human genes is estimated to be between 30,000 and 130,000.

A Practical Implication:

Scientists can now manipulate DNA and can therefore manipulate inherited characteristics of crops, bacteria, and other organisms, giving them new combinations of characteristics not found before and therefore demonstrating that characteristics are inherited and can be altered, as predicted by evolutionary theory. These new capabilities pose novel problems and hold new promise for biological diversity. On the one hand, we may be able to help rare, endangered species by increasing their genetic variability or by overcoming some of their less adaptive genetic characteristics that result from genetic drift. On the other hand, we may inadvertently create superpests, predators, or competitors of endangered species. Such new organisms may be to our benefit, but we must be careful not to release into the environment new strains that can reproduce rapidly and become unexpected pests. Genetic engineering poses new challenges for the environment, as we will discuss in later chapters. (We discuss some environmental implications of genetic engineering in Chapters 11 and 13.)

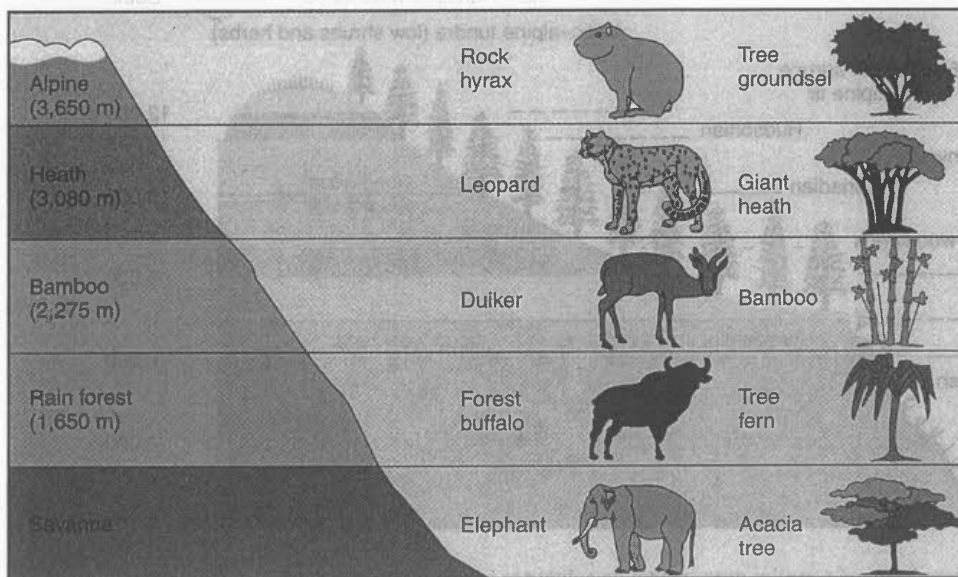


Figure 7.21 ■ Changes in the distribution of animals with elevation on a typical mountain in Kenya. (Source: From C. B. Cox, I. N. Healey, and P. D. Moore, *Biogeography* [New York: Halsted, 1973].)



Polar Bears and the Reasons People Value Biodiversity

In 2008, polar bears were listed as threatened species under the U.S. Endangered Species Act. Worldwide an estimated 20,000 to 25,000 polar bears roam the arctic, hunting and living primarily off of ringed and bearded seals. Of these, about 5,000 live within the United States. Refer back to the reasons that people value biodiversity. Read up on polar bears and decide which of these reasons apply to this species. In particular, consider the questions that follow.

Critical Thinking Questions

1. As a top predator, is the polar bear a necessary part of its ecosystem? (Hint: Consider the polar bear's ecological niche.)
2. Do the Inuit who live among polar bears value them as part of the arctic diversity of life? (This will take some additional study on your part.)
3. Based on what you have learned, what are the primary reasons, of the eight discussed at the beginning of the chapter, that the polar bear has been listed as threatened?

Additional information about polar bears can be found at the following:

U.S. Department of Interior Ruling on the Polar Bear:

http://alaska.fws.gov/fisheries/mmm/polarbear/pdf/Polar_Bear_Final_Rule.pdf

About Polar Bears as a Species and Its Habitat and Requirements:

Polar Bears: Proceedings of the 14th Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 20–24 June 2005, Seattle Washington, USA. Available at the International Union for the Conservation of Nature (IUCN) website: <http://www.iucnredlist.org/search/details.php/22823/summ>

Global Warming and Polar Bears:

Derocher, A.E., Nicholas J. Lunn, and Ian Stirling (2004). "Polar Bears in a Warming Climate." *Integer. Comp. Biol.* 44: 13–176.

SUMMARY

- Biological evolution—the change in inherited characteristics of a population from generation to generation—is responsible for the development of the many species of life on Earth. Four processes that lead to evolution are mutation, natural selection, migration, and genetic drift.
- Biological diversity involves three concepts: genetic diversity (the total number of genetic characteristics), habitat diversity (the diversity of habitats in a given unit area), and species diversity. Species diversity, in turn, involves three ideas: species richness (the total number of species), species evenness (the relative abundance of species), and species dominance (the most abundant species).
- About 1.4 million species have been identified and named. Insects and plants make up most of these species. With further explorations, especially in tropical areas, the number of identified species, especially of invertebrates and plants, will increase.
- Species engage in three basic kinds of interactions: competition, symbiosis, and predation–parasitism.

Each type of interaction affects evolution, the persistence of species, and the overall diversity of life. It is important to understand that organisms have evolved together so that predator, parasite, prey, competitor, and symbiont have adjusted to one another. Human interventions frequently upset these adjustments.

- The competitive exclusion principle states that two species that have exactly the same requirements cannot coexist in exactly the same habitat; one must win. The reason that more species do not die out from competition is that they have developed a particular niche and thus avoid competition.
- The number of species in a given habitat is affected by many factors, including latitude, elevation, topography, the severity of the environment, and the diversity of the habitat. Predation and moderate disturbances, such as fire, can actually increase the diversity of species. The number of species also varies over time. Of course, people affect diversity as well.

REEXAMINING THEMES AND ISSUES



Human Population

The growth of human populations has decreased biological diversity. If the human population continues to grow, pressures will continue on endangered species, and maintaining existing biological diversity will be an ever-greater challenge.

Sustainability

Sustainability involves more than just having many individuals of a species. For a species to persist, its life requirements must be present and its habitat must be in good condition. A diversity of habitats enables more species to persist.



Global Perspective

For several billion years, life has affected the environment on a global scale. These global effects have in turn affected biological diversity. Life added oxygen to the atmosphere and removed carbon dioxide, thereby making animal life possible.



Urban World

People have rarely thought about cities as having any beneficial effects on biological diversity. However, in recent years, there has been a growing realization that cities can contribute in important ways to the conservation of biological diversity. This topic will be discussed in Chapter 28.



People and Nature

People have always treasured the diversity of life, but we have been one of the main causes of the loss in diversity.



Science and Values

Perhaps no environmental issue causes more debate, is more central to arguments over values, or has greater emotional importance to people than biological diversity. Concern with specific endangered species has been at the heart of many political controversies. The path to resolving these conflicts and debates involves a clear understanding of the values at issue as well as knowledge about species and their habitat requirements and the role of biological diversity in life's history on Earth.

KEY TERMS

adaptive radiation **123**
biological diversity **119**
biological evolution **120**
competitive exclusion principle **131**
ecological niche **134**

founder effect **123**
gene **120**
genetic drift **123**
habitat **134**
migration **122**

mutation **121**
natural selection **121**
species **121**
symbiosis **135**
symbiont **135**

STUDY QUESTIONS

1. Why do introduced species often become pests?
2. On which of the following planets would you expect a greater diversity of species? (a) A planet with intense tectonic activities (b) A tectonically dead planet (Remember that tectonics refers to the geologic processes that involve the movement of tectonic plates and continents, processes that lead to mountain building, and so forth.)
3. You are going to conduct a survey of national parks. What relationship would you expect to find between the number of species of trees and the size of the parks?