Biodiversity and Evolution

4

Why Should We Care about the American Alligator?

CORE CASE STUDY

The American alligator (Figure 4-1), North America's largest reptile, has no natural predators except for humans, and it plays a number of important roles in the ecosystems where it is found. This species outlived the dinosaurs and has been able to survive numerous dramatic changes in the earth's environmental conditions.

But starting in the 1930s, these alligators faced a new challenge. Hunters began killing them in large numbers for their exotic meat and their supple belly skin, used to make shoes, belts, and pocketbooks. Other people hunted alligators for sport or out of hatred. By the 1960s, hunters and poachers had wiped out 90% of the alligators in the U.S. state of Louisiana, and the alligator population in the Florida Everglades was also near extinction.

Those who did not care much for the American alligator were probably not aware of its important ecological role—its *niche*—in subtropical wetland communities. These alligators dig deep depressions, or gator holes, which hold freshwater during dry spells, serve as refuges for aquatic life, and supply freshwater and food for fish, insects, snakes, turtles, birds, and other animals. Large alligator nesting mounds provide nesting and feeding sites for species of herons and egrets, and red-bellied turtles use old gator nests for incubating their eggs. These alligators eat large numbers of gar, a predatory fish. This helps maintain populations of game fish such as bass and bream.

As alligators move from gator holes to nesting mounds, they help keep areas of open water free of invading vegetation. Without these free ecosystem services, freshwater ponds and coastal wetlands where these alligators live would be filled in with shrubs and trees, and dozens of species would disappear from these ecosystems. Some ecologists classify the American alligator as a *keystone species* because of its important ecological role in helping to maintain the structure, function, and sustainability of the ecosystems where it is found. And, in 2008, scientists began analyzing the blood of the American alligator to identify compounds that could kill a variety of harmful bacteria, including those that have become resistant to commonly used antibiotics.

In 1967, the U.S. government placed the American alligator on the endangered species list. Protected from hunters, the population made a strong comeback in many areas by 1975—too strong, according to those who find alligators in their backyards and swimming pools, and to duck hunters whose retriever dogs are sometimes eaten by alligators. In 1977, the U.S. Fish and Wildlife Service reclassified the American alligator as a *threatened* species in the U.S. states of Florida, Louisiana, and Texas, where 90% of the animals live. Today there are 1–2 million American alligators in Florida, and the state now allows property owners to kill alligators that stray onto their land.

To biologists, the comeback of the American alligator is an important success story in wildlife conservation. This tale illustrates how each species in a community or ecosystem fills a unique role, and it highlights how interactions between species can affect ecosystem structure and function. In this chapter, we will examine biodiversity, with an emphasis on species diversity, and the theory of how the earth's diverse species arose.

A. & J. Visage/Peter Arnold, Inc.

Figure 4-1 The American alligator plays an important ecological role in its marsh and swamp habitats in the southeastern United States. Since being classified as an endangered species in 1967, it has recovered enough to have its status changed from endangered to threatened—an outstanding success story in wildlife conservation.

Key Questions and Concepts

4-1 **What is biodiversity and why is it important?**

CONCEPT 4-1 The biodiversity found in genes, species, ecosystems, and ecosystem processes is vital to sustaining life on earth.

4-2 **Where do species come from?**

CONCEPT 4-2A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.

CONCEPT 4-2B Populations evolve when genes mutate and give some individuals genetic traits that enhance their abilities to survive and to produce offspring with these traits (natural selection).

4-3 **How do geological processes and climate change affect evolution?**

CONCEPT 4-3 Tectonic plate movements, volcanic eruptions, earthquakes, and climate change have shifted wildlife habitats, wiped out large numbers of species, and created opportunities for the evolution of new species.

4-4 **How do speciation, extinction, and human activities affect biodiversity?**

CONCEPT 4-4A As environmental conditions change, the balance between formation of new species and extinction of existing species determines the earth's biodiversity.

CONCEPT 4-4B Human activities can decrease biodiversity by causing the premature extinction of species and by destroying or degrading habitats needed for the development of new species.

4-5 **What is species diversity and why is it important?**

CONCEPT 4-5 Species diversity is a major component of biodiversity and tends to increase the sustainability of ecosystems.

4-6 **What roles do species play in ecosystems?**

CONCEPT 4-6A Each species plays a specific ecological role called its niche.

CONCEPT 4-6B Any given species may play one or more of five important roles—native, nonnative, indicator, keystone, or foundation roles—in a particular ecosystem.

Note: Supplements 2 (p. S4), 4 (p. S20), 6 (p. S39), 7 (p. S46), 8 (p. S47), and 13 (p. S78) can be used with this chapter.

There is grandeur to this view of life . . .
that, whilst this planet has gone cycling on . . .
endless forms most beautiful and most wonderful
have been, and are being, evolved.

CHARLES DARWIN

4-1 What Is Biodiversity and Why Is It Important?

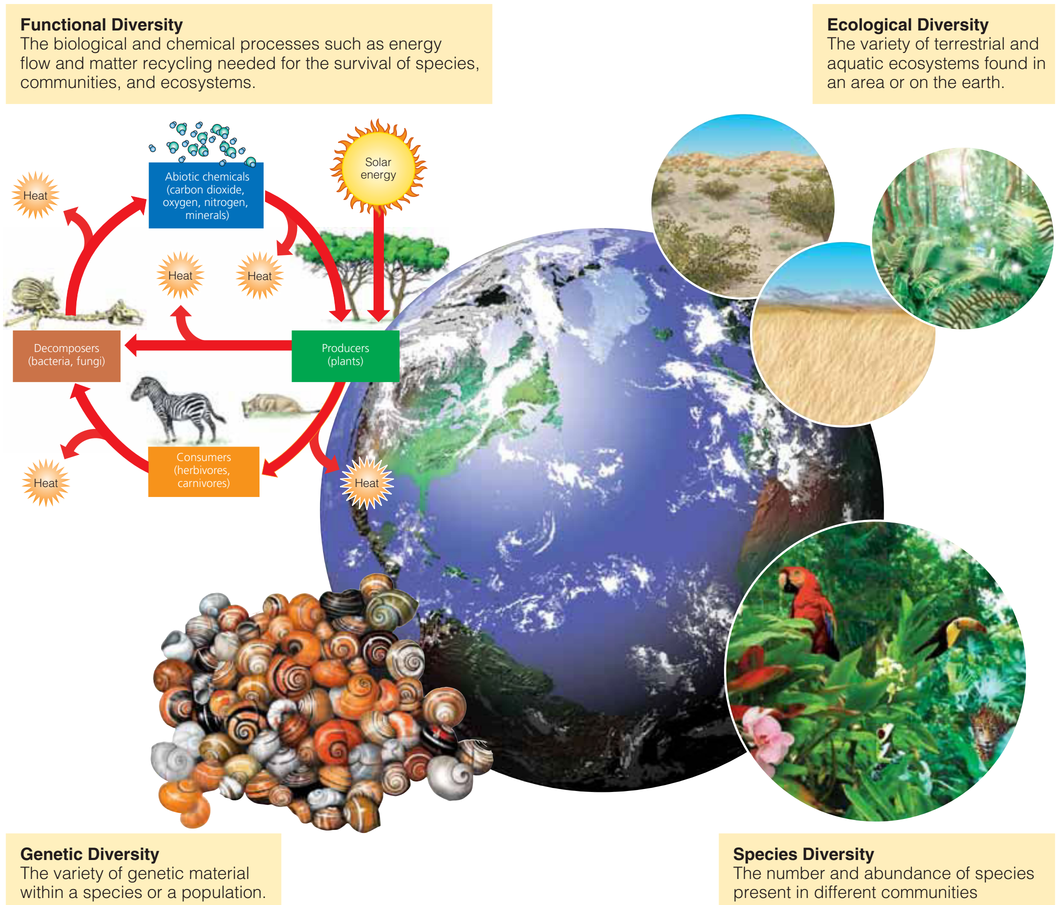
▶ **CONCEPT 4-1 The biodiversity found in genes, species, ecosystems, and ecosystem processes is vital to sustaining life on earth.**

Biodiversity Is a Crucial Part of the Earth's Natural Capital

Biological diversity, or **biodiversity,** is the variety of the earth's species, the genes they contain, the ecosystems in which they live, and the ecosystem processes such as energy flow and nutrient cycling that sustain all life (Figure 4-2). Biodiversity is a vital renewable resource (**Concept 4-1**).

So far, scientists have identified about 1.8 million of the earth's 4 million to 100 million species, and every year, thousands of new species are identified. The identified species include almost a million species of insects, 270,000 plant species, and 45,000 vertebrate animal species. Later in this chapter, we look at the scientific theory of how such a great variety of life forms came to be, and we consider the importance of species diversity.

Links: CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.



CENGAGENOW™ **Active Figure 4-2** **Natural capital:** the major components of the earth's *biodiversity*—one of the earth's most important renewable resources. *See an animation based on this figure at* CengageNOW™. **Question:** What are three examples of how people, in their daily living, intentionally or unintentionally degrade each of these types of biodiversity?

Species diversity is the most obvious, but not the only, component of biodiversity. Another important component is *genetic diversity* (Figure 3-5, p. 53). The earth's variety of species contains an even greater variety of genes. Genetic diversity enables life on the earth to adapt to and survive dramatic environmental changes. In other words, genetic diversity is vital to the sustainability of life on earth.

Ecosystem diversity—the earth's variety of deserts, grasslands, forests, mountains, oceans, lakes, rivers, and wetlands is another major component of biodiversity. Each of these ecosystems is a storehouse of genetic and species diversity.

Yet another important component of biodiversity is *functional diversity*—the variety of processes such as matter cycling and energy flow taking place within ecosystems (Figure 3-12, p. 60) as species interact with one another in food chains and webs. Part of the importance of the American alligator (Figure 4-1) is its role in supporting these processes within its ecosystems, which help to maintain other species of animals and plants that live there.

THINKING ABOUT
Alligators and Biodiversity

CORE CASE STUDY

What are three ways in which the American alligator (**Core Case Study**) supports one or more of the four components of biodiversity within its environment?

The earth's biodiversity is a vital part of the natural capital that keeps us alive. It supplies us with food, wood, fibers, energy, and medicines—all of which represent hundreds of billions of dollars in the world economy each year. Biodiversity also plays a role in preserving the quality of the air and water and maintaining the fertility of soils. It helps us to dispose of wastes and to control populations of pests. In carrying out these free ecological services, which are also part of the earth's natural capital (**Concept 1-1A**, p. 6), biodiversity helps to sustain life on the earth.

CONCEPT LINK

Because biodiversity is such an important concept and so vital to sustainability, we are going to take a grand tour of biodiversity in this and the next seven chapters. This chapter focuses on the earth's variety of species, how these species evolved, and the major roles that species play in ecosystems. Chapter 5 examines how different interactions among species help to control population sizes and promote biodiversity. Chapter 6 uses principles of population dynamics developed in Chapter 5 to look at human population growth and its effects on biodiversity. Chapters 7 and 8, respectively, look at the major types of terrestrial and aquatic ecosystems that make up a key component of biodiversity. Then, the next three chapters examine major threats to species diversity (Chapter 9), terrestrial biodiversity (Chapter 10), and aquatic biodiversity (Chapter 11), and solutions for dealing with these threats.

4-2 Where Do Species Come From?

▶ **CONCEPT 4-2A The scientific theory of evolution explains how life on earth changes over time through changes in the genes of populations.**

▶ **CONCEPT 4-2B Populations evolve when genes mutate and give some individuals genetic traits that enhance their abilities to survive and to produce offspring with these traits (natural selection).**

Biological Evolution by Natural Selection Explains How Life Changes over Time

How did we end up with an amazing array of 4 million to 100 million species? The scientific answer involves **biological evolution:** the process whereby earth's life changes over time through changes in the genes of populations (**Concept 4-2A**).

The idea that organisms change over time and are descended from a single common ancestor has been around in one form or another since the early Greek philosophers. But no one had come up with a credible explanation of how this could happen until 1858 when naturalists Charles Darwin (1809–1882) and Alfred Russel Wallace (1823–1913) independently proposed the concept of *natural selection* as a mechanism for biological evolution. Although Wallace also proposed the idea of natural selection, it was Darwin, who meticulously gathered evidence for this idea and published it in 1859 in his book, *On the Origin of Species by Means of Natural Selection*.

Darwin and Wallace observed that organisms must constantly struggle to obtain enough food and other resources to survive and reproduce. They also observed that individuals in a population with a specific advantage over other individuals are more likely to survive, reproduce, and have offspring with similar survival skills. The advantage was due to a characteristic, or *trait,* possessed by these individuals but not by others.

Darwin and Wallace concluded that these survival traits would become more prevalent in future populations of the species through a process called **natural selection,** which occurs when some individuals of a population have genetically based traits that enhance their ability to survive and produce offspring with the same traits. A change in the genetic characteristics of a population from one generation to another is known as *biological evolution,* or simply *evolution.*

A huge body of field and laboratory evidence has supported this idea. As a result, biological evolution through natural selection has become an important scientific theory. According to this theory, life has evolved into six major groups of species, called *kingdoms,* as a result of natural selection. This view sees the development of life as an ever-branching tree of species diversity, sometimes called the *tree of life* (Figure 4-3).

This scientific theory generally explains how life has changed over the past 3.7 billion years and why life is so diverse today. However, there are still many unanswered questions and scientific debates about the details of evolution by natural selection. Such continual questioning and discussion is an important way in which science advances our knowledge of how the earth works.

CENGAGENOW™ Get a detailed look at early biological evolution by natural selection—the roots of the tree of life—at CengageNOW™.

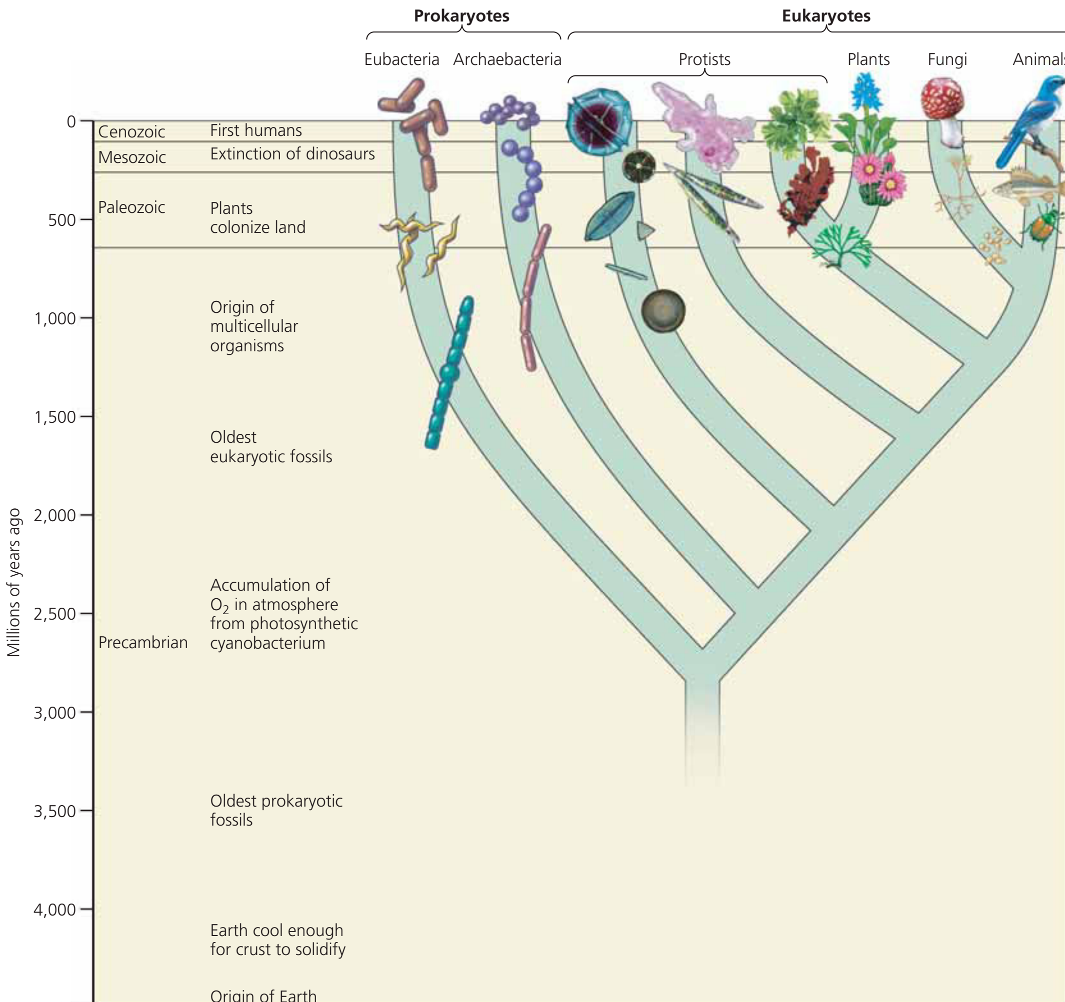


Figure 4-3 Overview of the evolution of life on the earth into six major kingdoms of species as a result of natural selection. For more details, see p. S46 in Supplement 7.

The Fossil Record Tells Much of the Story of Evolution

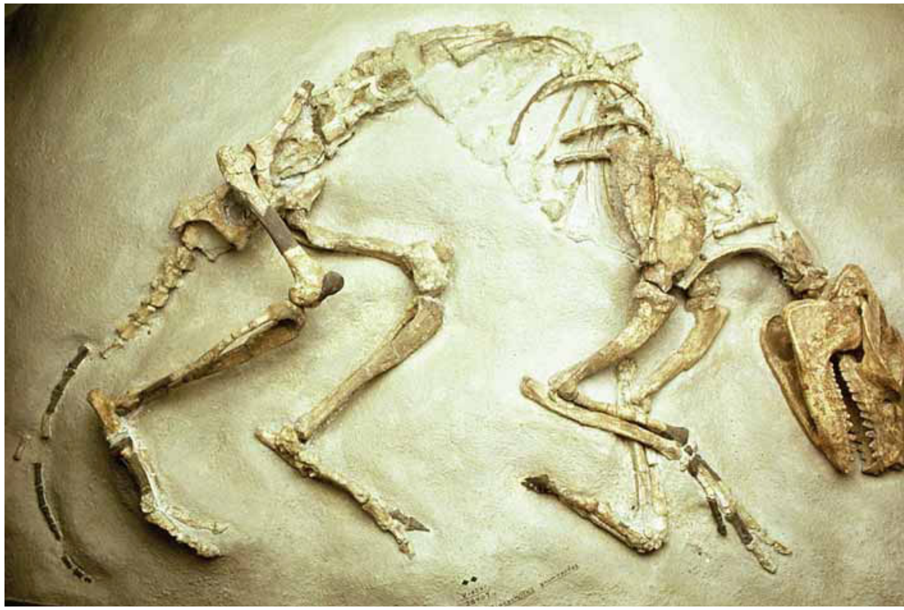
Most of what we know of the earth's life history comes from **fossils:** mineralized or petrified replicas of skeletons, bones, teeth, shells, leaves, and seeds, or impressions of such items found in rocks. Also, scientists drill cores from glacial ice at the earth's poles and on mountaintops and examine the kinds of life found at different layers. Fossils provide physical evidence of ancient organisms and reveal what their internal structures looked like (Figure 4-4, p. 82).

The world's cumulative body of fossils found is called the *fossil record.* This record is uneven and incomplete. Some forms of life left no fossils, and some fossils have decomposed. The fossils found so far probably represent only 1% of all species that have ever lived. Trying to reconstruct the development of life with so little evidence—a challenging scientific detective game—is the work of paleontologists. **GREEN CAREER:** Paleontologist

The Genetic Makeup of a Population Can Change

The process of biological evolution by natural selection involves changes in a population's genetic makeup through successive generations. Note that *populations—not individuals—evolve by becoming genetically different.*

Figure 4-4 Fossilized skeleton of an herbivore that lived during the Cenozoic era from 26–66 million years ago.



Kevin Schafer/Peter Arnold, Inc.

The first step in this process is the development of *genetic variability* in a population. This genetic variety occurs through **mutations:** *random* changes in the structure or number of DNA molecules in a cell that can be inherited by offspring (Figure 11, p. S43, in Supplement 6). Most mutations result from random changes that occur in coded genetic instructions when DNA molecules are copied each time a cell divides and whenever an organism reproduces. In other words, this copying process is subject to random errors. Some mutations also occur from exposure to external agents such as radioactivity, X rays, and natural and human-made chemicals (called *mutagens*).

Mutations can occur in any cell, but only those taking place in reproductive cells are passed on to offspring. Sometimes a mutation can result in a new genetic trait that gives an individual and its offspring better chances for survival and reproduction under existing environmental conditions or when such conditions change.

Individuals in Populations with Beneficial Genetic Traits Can Leave More Offspring

The next step in biological evolution is *natural selection,* which occurs when some individuals of a population have genetically based traits (resulting from mutations) that enhance their ability to survive and produce offspring with these traits (**Concept 4-2B**).

An **adaptation,** or **adaptive trait,** is any heritable trait that enables an individual organism to survive through natural selection and to reproduce more than other individuals under prevailing environmental conditions. For natural selection to occur, a trait must be *heritable,* meaning that it can be passed from one generation to another. The trait must also lead to **differential reproduction,** which enables individuals with the trait to leave more offspring than other members of the population leave.

For example, in the face of snow and cold, a few gray wolves in a population that have thicker fur than other wolves might live longer and thus produce more offspring than those without thicker fur who do not live as long. As those individuals with thicker fur mate, genes for thicker fur spread throughout the population and individuals with those genes increase in number and pass this helpful trait on to their offspring. Thus, the concept of natural selection explains how populations adapt to changes in environmental conditions.

Genetic resistance is the ability of one or more organisms in a population to tolerate a chemical designed to kill it. For example, an organism might have a gene that allows it to break the chemical down into harmless substances. Another important example of natural selection at work is the evolution of antibiotic resistance in disease-causing bacteria. Scientists have developed antibacterial drugs (antibiotics) to fight these bacteria, and the drugs have become a driving force of natural selection. The few bacteria that are genetically resistant to the drugs (because of some trait they possess) survive and produce more offspring than the bacteria that were killed by the drugs could have produced. Thus, the antibiotic eventually loses its effectiveness, as resistant bacteria rapidly reproduce and those that are susceptible to the drug die off (Figure 4-5).

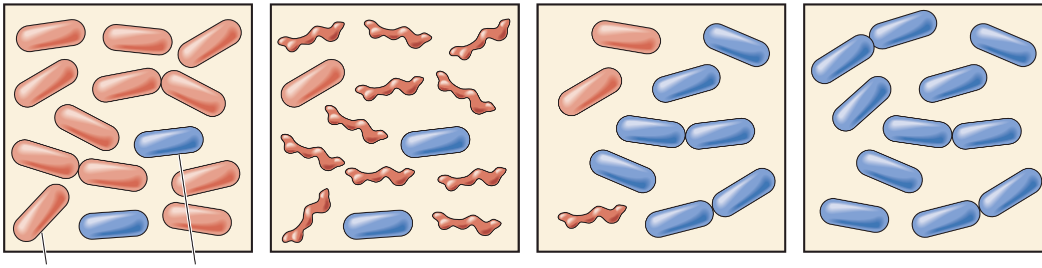


Figure 4-5 *Evolution by natural selection.* **(a)** A population of bacteria is exposed to an antibiotic, which **(b)** kills all but those possessing a trait that makes them resistant to the drug. **(c)** The resistant bacteria multiply and eventually **(d)** replace the nonresistant bacteria.

Note that natural selection acts on individuals, but evolution occurs in populations. In other words, populations can evolve when genes change or mutate and give some individuals genetic traits that enhance their ability to survive and to produce offspring with these traits (natural selection) (**Concept 4-2B**).

CENGAGENOW™ How many moths can you eat? Find out and learn more about adaptation at CengageNOW.

Another way to summarize the process of biological evolution by natural selection is: *Genes mutate, individuals are selected, and populations evolve that are better adapted to survive and reproduce under existing environmental conditions.*

When environmental conditions change, a population of a species faces three possible futures: *adapt* to the new conditions through natural selection, *migrate* (if possible) to an area with more favorable conditions, or *become extinct.*

A remarkable example of evolution by natural selection is human beings. We have evolved certain traits that have allowed us to take over much of the world (see Case Study below).

■ CASE STUDY

How Did Humans Become Such a Powerful Species?

Like many other species, humans have survived and thrived because we have certain traits that allow us to adapt to and modify parts of the environment to increase our survival chances.

Evolutionary biologists attribute our success to three adaptations: *strong opposable thumbs* that allow us to grip and use tools better than the few other animals that have thumbs can do, an ability to *walk upright,* and a *complex brain.* These adaptations have helped us develop weapons, protective devices, and technologies that extend our limited senses and make up for some of our deficiencies. Thus, in just a twitch of the 3.56-billion-year history of life on earth, we have developed powerful technologies and taken over much of the earth's life-support systems and net primary productivity.

But adaptations that make a species successful during one period of time may not be enough to ensure the species' survival when environmental conditions change. This is no less true for humans, and some environmental conditions are now changing rapidly, largely due to our own actions.

The *good news* is that one of our adaptations—our powerful brain—may enable us to live more sustainably by understanding and copying the ways in which nature has sustained itself for billions of years, despite major changes in environmental conditions (**Concept 1-6**, p. 23).

CONCEPT LINK

THINKING ABOUT
Human Adaptations

An important adaptation of humans is strong opposable thumbs, which allow us to grip and manipulate things with our hands. Make a list of the things you could not do without the use of your thumbs.

Adaptation through Natural Selection Has Limits

In the not-too-distant future, will adaptations to new environmental conditions through natural selection allow our skin to become more resistant to the harmful effects of ultraviolet radiation, our lungs to cope with air pollutants, and our livers to better detoxify pollutants?

According to scientists in this field, the answer is *no* because of two limits to adaptations in nature through natural selection. *First,* a change in environmental conditions can lead to such an adaptation only for genetic traits already present in a population's gene pool or for traits resulting from mutations.

Second, even if a beneficial heritable trait is present in a population, the population's ability to adapt may be limited by its reproductive capacity. Populations of genetically diverse species that reproduce quickly—such as weeds, mosquitoes, rats, bacteria, or cockroaches—often adapt to a change in environmental conditions in a short time. In contrast, species that cannot produce large numbers of offspring rapidly—such as elephants, tigers, sharks, and humans—take a long time (typically thousands or even millions of years) to adapt through natural selection.

Three Common Myths about Evolution through Natural Selection

According to evolution experts, there are three common misconceptions about biological evolution through natural selection. One is that "survival of the fittest" means "survival of the strongest." To biologists, *fitness* is a measure of reproductive success, not strength. Thus, the fittest individuals are those that leave the most descendants.

Another misconception is that organisms develop certain traits because they need or want them. A giraffe does not have a very long neck because it needs or wants it in order to feed on vegetation high in trees. Rather, some ancestor had a gene for long necks that gave it an advantage over other members of its population in getting food, and that giraffe produced more offspring with long necks.

A third misconception is that evolution by natural selection involves some grand plan of nature in which species become more perfectly adapted. From a scientific standpoint, no plan or goal of genetic perfection has been identified in the evolutionary process. Rather, it appears to be a random, branching process that results in a great variety of species (Figure 4-3).

4-3 How Do Geological Processes and Climate Change Affect Evolution?

▶ CONCEPT 4-3 Tectonic plate movements, volcanic eruptions, earthquakes, and climate change have shifted wildlife habitats, wiped out large numbers of species, and created opportunities for the evolution of new species.

Geological Processes Affect Natural Selection

The earth's surface has changed dramatically over its long history. Scientists have discovered that huge flows of molten rock within the earth's interior break its surface into a series of gigantic solid plates, called *tectonic plates.* For hundreds of millions of years, these plates have drifted slowly atop the planet's mantle (Figure 4-6).

This process has had two important effects on the evolution and location of life on the earth. *First,* the locations of continents and oceanic basins greatly influence the earth's climate and thus help determine where plants and animals can live.

Second, the movement of continents has allowed species to move, adapt to new environments, and form new species through natural selection. When continents join together, populations can disperse to new areas and adapt to new environmental conditions. And when continents separate, populations either evolve under the new conditions or become extinct.

Earthquakes can also affect biological evolution by causing fissures in the earth's crust that can separate and isolate populations of species. Over long periods of time, this can lead to the formation of new species as each isolated population changes genetically in response to new environmental conditions. And *volcanic eruptions* affect biological evolution by destroying habitats and reducing or wiping out populations of species (**Concept 4-3**).

Climate Change and Catastrophes Affect Natural Selection

Throughout its long history, the earth's climate has changed drastically. Sometimes it has cooled and covered much of the earth with ice. At other times it has warmed, melted ice, and drastically raised sea levels. Such alternating periods of cooling and heating have led to advances and retreats of ice sheets at high latitudes over much of the northern hemisphere, most recently, about 18,000 years ago (Figure 4-7).

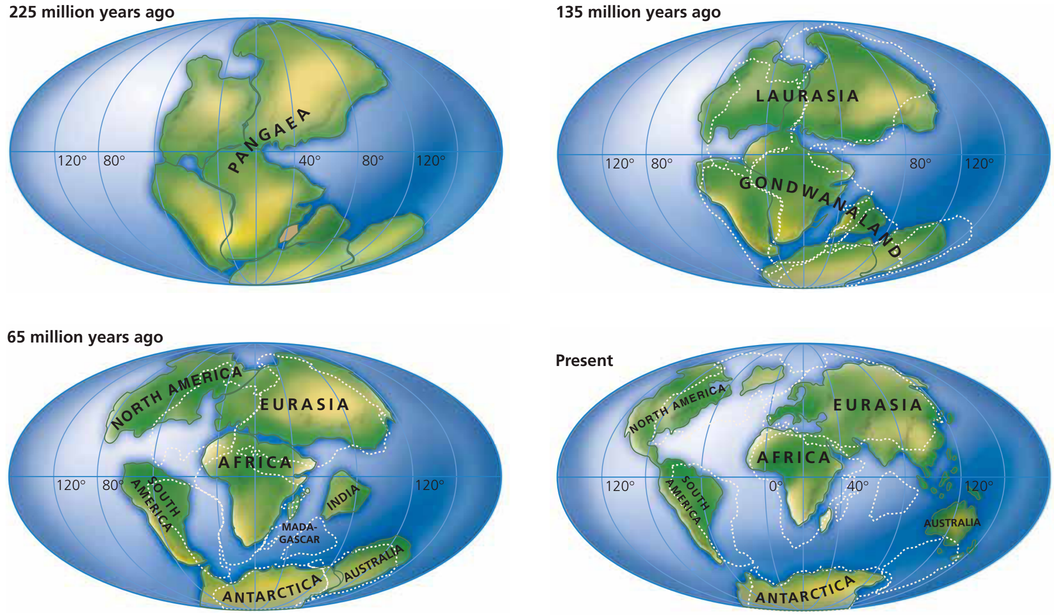


Figure 4-6 Over millions of years, the earth's continents have moved very slowly on several gigantic tectonic plates. This process plays a role in the extinction of species, as land areas split apart, and also in the rise of new species when isolated land areas combine. Rock and fossil evidence indicates that 200–250 million years ago, all of the earth's present-day continents were locked together in a supercontinent called Pangaea (top left). About 180 million years ago, Pangaea began splitting apart as the earth's tectonic plates separated, eventually resulting in today's locations of the continents (bottom right). **Question:** How might an area of land splitting apart cause the extinction of a species?

These long-term climate changes have a major effect on biological evolution by determining where different types of plants and animals can survive and thrive and by changing the locations of different types of ecosystems such as deserts, grasslands, and forests (**Concept 4-3**). Some species became extinct because the climate changed too rapidly for them to survive, and new species evolved to fill their ecological roles.

Another force affecting natural selection has been catastrophic events such as collisions between the earth and large asteroids. There have probably been many of these collisions during the earth's 4.5 billion years. Such impacts have caused widespread destruction of ecosystems and wiped out large numbers of species. But they have also caused shifts in the locations of ecosystems and created opportunities for the evolution of new species. On a long-term basis, the four **scientific principles of sustainability** (see back cover), especially biodiversity (Figure 4-2) have enabled life on earth to adapt to drastic changes in environmental conditions (Science Focus, p. 86). In other words, we live on a habitable planet. (See *The Habitable Planet,* Video 1, **www.learner.org/resources/series209.html**.)

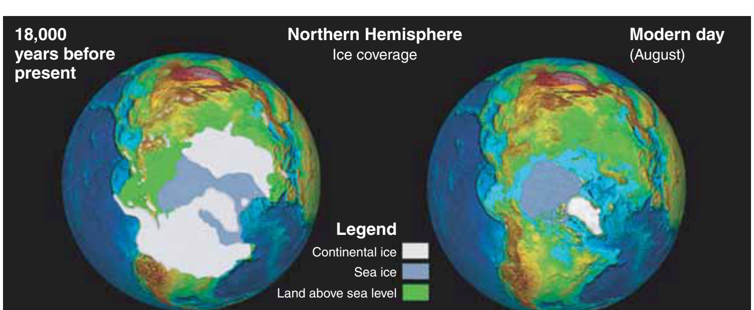


Figure 4-7 Changes in ice coverage in the northern hemisphere during the past 18,000 years. **Question:** What are two characteristics of an animal and two characteristics of a plant that natural selection would have favored as these ice sheets (left) advanced? (Data from the National Oceanic and Atmospheric Administration)

SCIENCE FOCUS

Earth Is Just Right for Life to Thrive

Life on the earth, as we know it, can thrive only within a certain temperature range, which depends on the liquid water that dominates the earth's surface. Most life on the earth requires average temperatures between the freezing and boiling points of water.

The earth's orbit is the right distance from the sun to provide these conditions. If the earth were much closer to the sun, it would be too hot—like Venus—for water vapor to condense and form rain. If it were much farther away, the earth's surface would be so cold—like Mars—that its water would exist only as ice. The earth also spins; if it did not, the side facing the sun would be too hot and the other side too cold for water-based life to exist.

The size of the earth is also just right for life. It has enough gravitational mass to keep its iron and nickel core molten and to keep the atmosphere—made up of light gaseous molecules required for life (such as N_2, O_2, CO_2, and H_2O)—from flying off into space.

Although life on earth has been enormously resilient and adaptive, it has benefitted from a favorable temperature range. During the 3.7 billion years since life arose, the average surface temperature of the earth has remained within the narrow range of 10–20 °C (50–68 °F), even with a 30–40% increase in the sun's energy output. One reason for this is the evolution of organisms that modify levels of the temperature-regulating gas carbon dioxide in the atmosphere as a part of the carbon cycle (Figure 3-18, p. 68)

For almost 600 million years, oxygen has made up about 21% of the volume of earth's atmosphere. If this oxygen content dropped to about 15%, it would be lethal for most forms of life. If it increased to about 25%, oxygen in the atmosphere would probably ignite into a giant fireball. The current oxygen content of the atmosphere is largely the result of producer and consumer organisms interacting in the carbon cycle. Also, because of the development of photosynthesizing bacteria that have been adding oxygen to the atmosphere for more than 2 billion years, an ozone sunscreen in the stratosphere protects us and many other forms of life from an overdose of ultraviolet radiation.

In short, this remarkable planet we live on is uniquely suited for life as we know it.

Critical Thinking

Design an experiment to test the hypothesis that various forms of life can maintain the oxygen content in the atmosphere at around 21% of its volume.

4-4 How Do Speciation, Extinction, and Human Activities Affect Biodiversity?

▶ **CONCEPT 4-4A As environmental conditions change, the balance between formation of new species and extinction of existing species determines the earth's biodiversity.**

▶ **CONCEPT 4-4B Human activities can decrease biodiversity by causing the premature extinction of species and by destroying or degrading habitats needed for the development of new species.**

How Do New Species Evolve?

Under certain circumstances, natural selection can lead to an entirely new species. In this process, called **speciation,** two species arise from one. For sexually reproducing species, a new species is formed when some members of a population have evolved to the point where they no longer can breed with other members to produce fertile offspring.

The most common mechanism of speciation (especially among sexually reproducing animals) takes place in two phases: geographic isolation and reproductive isolation. **Geographic isolation** occurs when different groups of the same population of a species become physically isolated from one another for long periods. For example, part of a population may migrate in search of food and then begin living in another area with different environmental conditions. Separation of populations can occur because of a physical barrier (such as a mountain range, stream, or road), a volcanic eruption or earthquake, or when a few individuals are carried to a new area by wind or flowing water.

In **reproductive isolation,** mutation and change by natural selection operate independently in the gene pools of geographically isolated populations. If this process continues long enough, members of the geographically and reproductively isolated populations may become so different in genetic makeup that they cannot produce live, fertile offspring if they are rejoined. Then one species has become two, and speciation has occurred (Figure 4-8).

For some rapidly reproducing organisms, this type of speciation may occur within hundreds of years. For most species, it takes from tens of thousands to millions

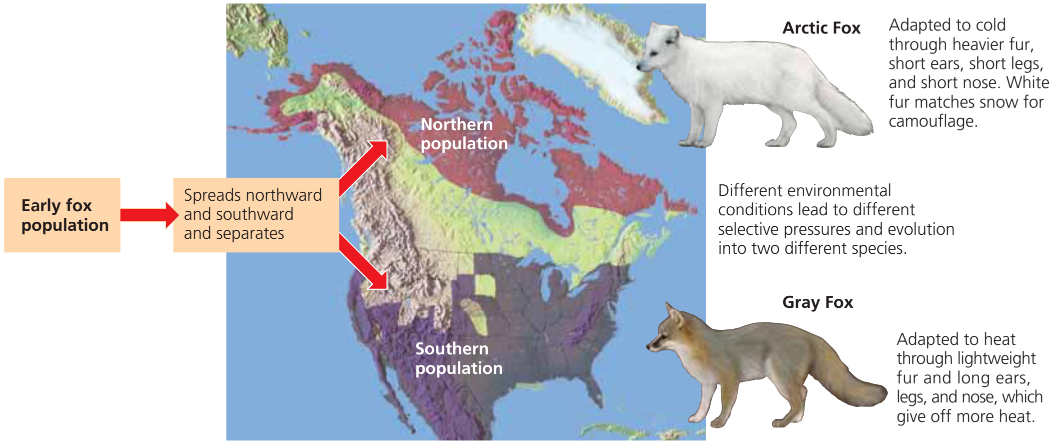


Figure 4-8 *Geographic isolation* can lead to reproductive isolation, divergence of gene pools, and speciation.

of years—making it difficult to observe and document the appearance of a new species.

CENGAGENOW™ Learn more about different types of speciation and ways in which they occur at CengageNOW.

Humans are playing an increasing role in the process of speciation. We have learned to shuffle genes from one species to another though artificial selection and more recently through genetic engineering (Science Focus, p. 88).

THINKING ABOUT
Speciation and American Alligators

CORE CASE STUDY

Imagine how a population of American alligators (**Core Case Study**) might have evolved into two species had they become separated, with one group evolving in a more northern climate. Describe some of the traits of the hypothetical northern species.

Michael P. Fogden/Bruce Coleman USA

Figure 4-9 Male golden toad in Costa Rica's high-altitude Monteverde Cloud Forest Reserve. This species has recently become extinct, primarily because changes in climate dried up its habitat.

Extinction Is Forever

Another process affecting the number and types of species on the earth is **extinction,** in which an entire species ceases to exist. Species that are found in only one area are called **endemic species** and are especially vulnerable to extinction. They exist on islands and in other unique small areas, especially in tropical rain forests where most species are highly specialized.

One example is the brilliantly colored golden toad (Figure 4-9) once found only in a small area of lush cloud rain forests in Costa Rica's mountainous region. Despite living in the country's well-protected Monteverde Cloud Forest Reserve, by 1989, the golden toad had apparently become extinct. Much of the moisture that supported its rain forest habitat came in the form of moisture-laden clouds blowing in from the Caribbean Sea. But warmer air from global climate change caused these clouds to rise, depriving the forests of moisture, and the habitat for the golden toad and many other species dried up. The golden toad appears to be one of the first victims of climate change caused largely by global warming. A 2007 study found that global warming has also contributed to the extinction of five other toad and frog species in the jungles of Costa Rica.

Extinction Can Affect One Species or Many Species at a Time

All species eventually become extinct, but drastic changes in environmental conditions can eliminate large groups of species. Throughout most of history, species have disappeared at a low rate, called **background**

SCIENCE FOCUS

We Have Developed Two Ways to Change the Genetic Traits of Populations

We have used **artificial selection** to change the genetic characteristics of populations with similar genes. In this process, we select one or more desirable genetic traits in the population of a plant or animal, such as a type of wheat, fruit, or dog. Then we use *selective breeding* to generate populations of the species containing large numbers of individuals with the desired traits. Note that artificial selection involves crossbreeding between genetic varieties of the same species and thus is not a form of speciation. Most, of the grains, fruits, and vegetables we eat are produced by artificial selection.

Artificial selection has given us food crops with higher yields, cows that give more milk, trees that grow faster, and many different types of dogs and cats. But traditional crossbreeding is a slow process. Also, it can combine traits only from species that are close to one another genetically.

Now scientists are using genetic engineering to speed up our ability to manipulate genes. **Genetic engineering,** or **gene splicing,** is the alteration of an organism's genetic material, through adding, deleting, or changing segments of its DNA (Figure 11, p. S43, in Supplement 6), to produce desirable traits or eliminate undesirable ones. It enables scientists to transfer genes between different species that would not interbreed in nature. For example, genes from a fish species can be put into a tomato plant to give it certain properties.

Scientists have used gene splicing to develop modified crop plants, new drugs, pest-resistant plants, and animals that grow rapidly (Figure 4-A). They have also created genetically engineered bacteria to extract minerals such as copper from their underground ores and to clean up spills of oil and other toxic pollutants.

Application of our increasing genetic knowledge is filled with great promise, but it raises some serious ethical and privacy issues. For example, some people have genes that make them more likely to develop certain genetic diseases or disorders. We now have the power to detect these genetic deficiencies, even before birth. Questions of ethics and morality arise over how this knowledge and technology will be applied, who will benefit, and who might suffer from it.

R. L. Brinster and R. E. Hammer/School of Veterinary Medicine, University of Pennsylvania

Figure 4-A An example of genetic engineering. The 6-month-old mouse on the left is normal; the same-age mouse on the right has a human growth hormone gene inserted in its cells. Mice with the human growth hormone gene grow two to three times faster and twice as large as mice without the gene. **Question:** How do you think the creation of such species might change the process of evolution by natural selection?

Further, what will be the environmental impacts of such applications? If genetic engineering could help all humans live in good health much longer than we do now, it might increase pollution, environmental degradation, and the strain on natural resources. More and more affluent people living longer and longer could create an enormous and ever-growing ecological footprint.

Some people dream of a day when our genetic engineering prowess could eliminate death and aging altogether. As one's cells, organs, or other parts wear out or become damaged, they could be replaced with new ones grown in genetic engineering facilities.

Assuming this is scientifically possible, is it morally acceptable to take this path? Who will decide? Who will regulate this new industry? Sometime in the not-too-distant future, will we be able to change the nature of what it means to be human? If so, how will it change? These are some of the most important and controversial ethical questions of the 21st century.

Another concern is that most new technologies have had unintended harmful consequences. For example, pesticides have helped protect crops from insect pests and disease. But their overuse has accelerated the evolution of pesticide-resistant species and has wiped out many natural predator insects that had helped to keep pest populations under control.

For these and other reasons, a backlash developed in the 1990s against the increasing use of genetically modified food plants and animals. Some protesters argue against using this new technology, mostly for ethical reasons. Others advocate slowing down the technological rush and taking a closer look at the short- and long-term advantages and disadvantages of genetic technologies.

Critical Thinking

What might be some beneficial and harmful effects on the evolutionary process if genetic engineering is widely applied to plants and animals?

extinction. Based on the fossil record and analysis of ice cores, biologists estimate that the average annual background extinction rate is one to five species for each million species on the earth.

In contrast, **mass extinction** is a significant rise in extinction rates above the background level. In such a catastrophic, widespread (often global) event, large groups of species (perhaps 25–70%) are wiped out in a geological period lasting up to 5 million years. Fossil and geological evidence indicate that the earth's species have experienced five mass extinctions (20–60 million years apart) during the past 500 million years. For example, about 250 million years ago, as much as 95% of all existing species became extinct.

Some biologists argue that a mass extinction should be distinguished by a low speciation rate as well as by a high rate of extinction. Under this more strict definition, there have been only three mass extinctions. As this subject is debated, the definitions will be refined, and one argument or the other will be adopted as the working hypothesis. Either way, there is substantial evidence that large numbers of species have become extinct several times in the past.

A mass extinction provides an opportunity for the evolution of new species that can fill unoccupied ecological roles or newly created ones. As environmental conditions change, the balance between formation of new species (speciation) and extinction of existing species determines the earth's biodiversity (**Concept 4-4A**). The existence of millions of species today means that speciation, on average, has kept ahead of extinction.

Extinction is a natural process. But much evidence indicates that humans have become a major force in the premature extinction of a growing number of species, as discussed further in Chapter 9.

4-5 What Is Species Diversity and Why Is It Important?

▶ **CONCEPT 4-5 Species diversity is a major component of biodiversity and tends to increase the sustainability of ecosystems.**

Species Diversity Includes the Variety and Abundance of Species in a Particular Place

An important characteristic of a community and the ecosystem to which it belongs is its **species diversity:** the number of different species it contains (**species richness**) combined with the relative abundance of individuals within each of those species (**species evenness**).

For example, a biologically diverse community such as a tropical rain forest or a coral reef (Figure 4-10, left) with a large number of different species (high species richness) generally has only a few members of each

Reinhard Dirscherl/Bruce Coleman USA

Alan Majchrowicz/Peter Arnold

Figure 4-10 *Variations in species richness and species evenness.* A coral reef (left), with a large number of different species (high species richness), generally has only a few members of each species (low species evenness). In contrast, a grove of aspen trees in Alberta, Canada, in the fall (right) has a small number of different species (low species richness), but large numbers of individuals of each species (high species evenness).

SCIENCE FOCUS

Species Richness on Islands

In the 1960s, ecologists Robert MacArthur and Edward O. Wilson began studying communities on islands to discover why large islands tend to have more species of a certain category such as insects, birds, or ferns than do small islands.

To explain these differences in species richness among islands of varying sizes, MacArthur and Wilson carried out research and used their findings to propose what is called the **species equilibrium model,** or the **theory of island biogeography.** According to this widely accepted scientific theory, the number of different species (species richness) found on an island is determined by the interactions of two factors: the rate at which new species immigrate to the island and the rate at which species become *extinct,* or cease to exist, on the island.

The model projects that, at some point, the rates of species immigration and species extinction should balance so that neither rate is increasing or decreasing sharply. This balance point is the equilibrium point that determines the island's average number of different species (species richness) over time. (The website **CengageNOW** has a great interactive animation of this model. Go to the end of any chapter for instructions on how to use it.)

According to the model, two features of an island affect the immigration and extinction rates of its species and thus its species diversity. One is the island's *size.* Small islands tend to have fewer species than large islands do because they make smaller targets for potential colonizers flying or floating toward them. Thus, they have lower immigration rates than larger islands do. In addition, a small island should have a higher extinction rate because it usually has fewer resources and less diverse habitats for its species.

A second factor is an island's *distance from the nearest mainland.* Suppose we have two islands about equal in size, extinction rates, and other factors. According to the model, the island closer to a mainland source of immigrant species should have the higher immigration rate and thus a higher species richness. The farther a potential colonizing species has to travel, the less likely it is to reach the island.

These factors interact to influence the relative species richness of different islands. Thus, larger islands closer to a mainland tend to have the most species, while smaller islands farther away from a mainland tend to have the fewest. Since MacArthur and Wilson presented their hypothesis and did their experiments, others have conducted more scientific studies that have born out their hypothesis, making it a widely accepted scientific theory.

Scientists have used this theory to study and make predictions about wildlife in *habitat islands*—areas of natural habitat, such as national parks and mountain ecosystems, surrounded by developed and fragmented land. These studies and predictions have helped scientists to preserve these ecosystems and protect their resident wildlife.

Critical Thinking

Suppose we have two national parks surrounded by development. One is a large park and the other is much smaller. Which park is likely to have the highest species richness? Why?

species (low species evenness). Biologist Terry Erwin found an estimated 1,700 different beetle species in a single tree in a tropical forest in Panama but only a few individuals of each species. On the other hand, an aspen forest community in Canada (Figure 4-10, right) may have only a few plant species (low species richness) but large numbers of each species (high species evenness).

The species diversity of communities varies with their *geographical location.* For most terrestrial plants and animals, species diversity (primarily species richness) is highest in the tropics and declines as we move from the equator toward the poles (see Figure 2, pp. S22–S23, in Supplement 4). The most species-rich environments are tropical rain forests, coral reefs (Figure 4-10, left), the ocean bottom zone, and large tropical lakes.

Scientists have sought to learn more about species richness by studying species on islands (Science Focus, above). Islands make good study areas because they are relatively isolated, and it is easier to observe species arriving and disappearing from islands than it would be to make such a study in other less isolated ecosystems.

CENGAGE**NOW**™ Learn about how latitude affects species diversity and about the differences between big and small islands at CengageNOW.

Species-Rich Ecosystems Tend to Be Productive and Sustainable

How does species richness affect an ecosystem? In trying to answer this question, ecologists have been conducting research to answer two related questions: Is plant productivity higher in species-rich ecosystems? And does species richness enhance the *stability,* or sustainability of an ecosystem? Research suggests that the answers to both questions may be "yes" but more research is needed before these scientific hypotheses can be accepted as scientific theories.

According to the first hypothesis, the more diverse an ecosystem is, the more productive it will be. That is, with a greater variety of producer species, an ecosystem will produce more plant biomass, which in turn will support a greater variety of consumer species.

A related hypothesis is that greater species richness and productivity will make an ecosystem more stable or sustainable. In other words, the greater the species richness and the accompanying web of feeding and biotic interactions in an ecosystem, the greater its sustainability, or ability to withstand environmental disturbances such as drought or insect infestations. According to this hypothesis, a complex ecosystem with many different species (high species richness) and the resulting variety of feeding paths has more ways to respond to most environmental stresses because it does not have "all its eggs in one basket."

Many studies support the idea that some level of species richness and productivity can provide insurance against catastrophe. In one prominent 11-year study, David Tilman and his colleagues at the University of Minnesota found that communities with high plant species richness produced a certain amount of biomass more consistently than did communities with fewer species. The species-rich communities were also less affected by drought and more resistant to invasions by new insect species. Because of their higher level of biomass, the species-rich communities also consumed more carbon dioxide and took up more nitrogen, thus taking more robust roles in the carbon and nitrogen cycles (**Concept 3-5**, p. 65). Later laboratory studies involved setting up artificial ecosystems in growth chambers where key variables such as temperature, light, and atmospheric gas concentrations could be controlled and varied. These studies have supported Tilman's findings.

CONCEPT LINK

Ecologists hypothesize that in a species-rich ecosystem, each species can exploit a different portion of the resources available. For example, some plants will bloom early and others will bloom late. Some have shallow roots to absorb water and nutrients in shallow soils, and others use deeper roots to tap into deeper soils.

There is some debate among scientists about how much species richness is needed to help sustain various ecosystems. Some research suggests that the average annual net primary productivity of an ecosystem reaches a peak with 10–40 producer species. Many ecosystems contain more than 40 producer species, but do not necessarily produce more biomass or reach a higher level of stability. Scientists are still trying to determine how many producer species are needed to enhance the sustainability of particular ecosystems and which producer species are the most important in providing such stability.

Bottom line: species richness appears to increase the productivity and stability or sustainability of an ecosystem (**Concept 4-5**). While there may be some exceptions to this, most ecologists now accept it as a useful hypothesis.

RESEARCH FRONTIER

Learning more about how biodiversity is related to ecosystem stability and sustainability. See **academic.cengage.com/biology/miller**.

4-6 What Roles Do Species Play in Ecosystems?

▶ **CONCEPT 4-6A Each species plays a specific ecological role called its niche.**

▶ **CONCEPT 4-6B Any given species may play one or more of five important roles—native, nonnative, indicator, keystone, or foundation roles—in a particular ecosystem.**

Each Species Plays a Unique Role in Its Ecosystem

An important principle of ecology is that *each species has a distinct role to play in the ecosystems where it is found* (**Concept 4-6A**). Scientists describe the role that a species plays in its ecosystem as its **ecological niche,** or simply **niche** (pronounced "nitch"). It is a species' way of life in a community and includes everything that affects its survival and reproduction, such as how much water and sunlight it needs, how much space it requires, and the temperatures it can tolerate. A species' niche should not be confused with its *habitat,* which is the place where it lives. Its niche is its pattern of living.

Scientists use the niches of species to classify them broadly as *generalists* or *specialists.* **Generalist species** have broad niches (Figure 4-11, right curve). They can live in many different places, eat a variety of foods, and

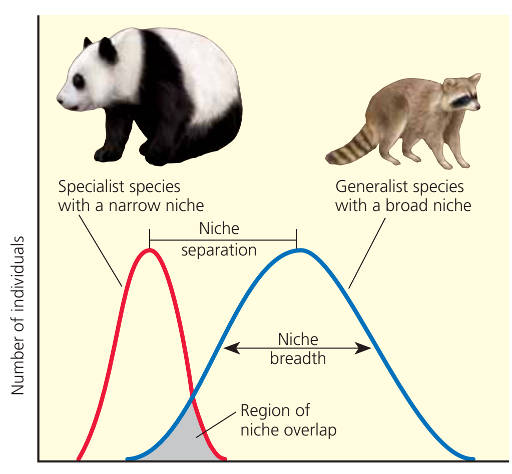


Figure 4-11 Specialist species such as the giant panda have a narrow niche (left) and generalist species such as a raccoon have a broad niche (right).

often tolerate a wide range of environmental conditions. Flies, cockroaches (see Case Study below), mice, rats, white-tailed deer, raccoons, and humans are generalist species.

In contrast, **specialist species** occupy narrow niches (Figure 4-11, left curve). They may be able to live in only one type of habitat, use one or a few types of food, or tolerate a narrow range of climatic and other environmental conditions. This makes specialists more prone to extinction when environmental conditions change.

For example, *tiger salamanders* breed only in fishless ponds where their larvae will not be eaten. China's *giant panda* (Figure 4-11, left) is highly endangered because of a combination of habitat loss, low birth rate, and its specialized diet consisting mostly of bamboo. Some shorebirds occupy specialized niches, feeding on crustaceans, insects, and other organisms on sandy beaches and their adjoining coastal wetlands (Figure 4-13).

Is it better to be a generalist or a specialist? It depends. When environmental conditions are fairly constant, as in a tropical rain forest, specialists have an advantage because they have fewer competitors. But under rapidly changing environmental conditions, the generalist usually is better off than the specialist.

THINKING ABOUT

The American Alligator's Niche

CORE CASE STUDY

Does the American alligator (**Core Case Study**) have a specialist or a generalist niche? Explain.

■ **CASE STUDY**

Cockroaches: Nature's Ultimate Survivors

Cockroaches (Figure 4-12), the bugs many people love to hate, have been around for 350 million years, outliving the dinosaurs. One of evolution's great success stories, they have thrived because they are *generalists.*

The earth's 3,500 cockroach species can eat almost anything, including algae, dead insects, fingernail clippings, salts in tennis shoes, electrical cords, glue, paper, and soap. They can also live and breed almost anywhere except in polar regions.

Some cockroach species can go for a month without food, survive for a month on a drop of water from a dishrag, and withstand massive doses of radiation. One species can survive being frozen for 48 hours.

Cockroaches usually can evade their predators—and a human foot in hot pursuit—because most species have antennae that can detect minute movements of air. They also have vibration sensors in their knee joints, and they can respond faster than you can blink your eye. Some even have wings. They have compound eyes that allow them to see in almost all directions at once. Each eye has about 2,000 lenses, compared to one in each of your eyes.

And, perhaps most significantly, they have high reproductive rates. In only a year, a single Asian cockroach and its offspring can add about 10 million new cockroaches to the world. Their high reproductive rate also helps them to quickly develop genetic resistance to almost any poison we throw at them.

Most cockroaches sample food before it enters their mouths and learn to shun foul-tasting poisons. They also clean up after themselves by eating their own dead and, if food is scarce enough, their living.

About 25 species of cockroach live in homes and can carry viruses and bacteria that cause diseases. On the other hand, cockroaches play a role in nature's food webs. They make a tasty meal for birds and lizards.

Niches Can Be Occupied by Native and Nonnative Species

Niches can be classified further in terms of specific roles that certain species play within ecosystems. Ecologists describe *native, nonnative, indicator, keystone,* and *foundation species.* Any given species may play one or more of these five roles in a particular community (**Concept 4-6B**).

Native species are those species that normally live and thrive in a particular ecosystem. Other species that migrate into or are deliberately or accidentally introduced into an ecosystem are called **nonnative species,** also referred to as *invasive, alien,* or *exotic species.*

Clemson University–USDA Cooperative Extension Slide Series

Figure 4-12 As generalists, cockroaches are among the earth's most adaptable and prolific species. This is a photo of an American cockroach.

Figure 4-13 Specialized feeding niches of various bird species in a coastal wetland. This specialization reduces competition and allows sharing of limited resources.

Some people tend to think of nonnative species as villains. In fact, most introduced and domesticated species of crops and animals, such as chickens, cattle, and fish from around the world, are beneficial to us. However, some nonnative species can threaten a community's native species and cause unintended and unexpected consequences. In 1957, for example, Brazil imported wild African bees to help increase honey production. Instead, the bees displaced domestic honeybees and reduced the honey supply.

Since then, these nonnative bee species—popularly known as "killer bees"—have moved northward into Central America and parts of the southwestern and southeastern United States. The wild African bees are not the fearsome killers portrayed in some horror movies, but they are aggressive and unpredictable. They have killed thousands of domesticated animals and an estimated 1,000 people in the western hemisphere, many of whom were allergic to bee stings.

Nonnative species can spread rapidly if they find a new more favorable niche. In their new niches, these species often do not face the predators and diseases they faced before, or they may be able to out-compete some native species in their new niches. We will examine this environmental threat in greater detail in Chapter 9.

Indicator Species Serve as Biological Smoke Alarms

Species that provide early warnings of damage to a community or an ecosystem are called **indicator species.** For example, the presence or absence of trout species in water at temperatures within their range of tolerance (Figure 3-10, p. 58) is an indicator of water quality because trout need clean water with high levels of dissolved oxygen.

Birds are excellent biological indicators because they are found almost everywhere and are affected quickly by environmental changes such as loss or fragmentation of their habitats and introduction of chemical pesticides. The populations of many bird species are declining. Butterflies are also good indicator species because their association with various plant species makes them vulnerable to habitat loss and fragmentation. Some amphibians are also classified as indicator species (Case Study below).

Using a living organism to monitor environmental quality is not new. Coal mining is a dangerous occupation, partly because of the underground presence of poisonous and explosive gases, many of which have no detectable odor. In the 1800s and early 1900s, coal miners took caged canaries into mines to act as early-warning sentinels. These birds sing loudly and often. If they quit singing for a long period and appeared to be distressed, miners took this as an indicator of the presence of poisonous or explosive gases and got out of the mine.

■ **CASE STUDY**

Why Are Amphibians Vanishing?

Amphibians (frogs, toads, and salamanders) live part of their lives in water and part on land. Populations of some amphibians, also believed to be indicator species, are declining throughout the world.

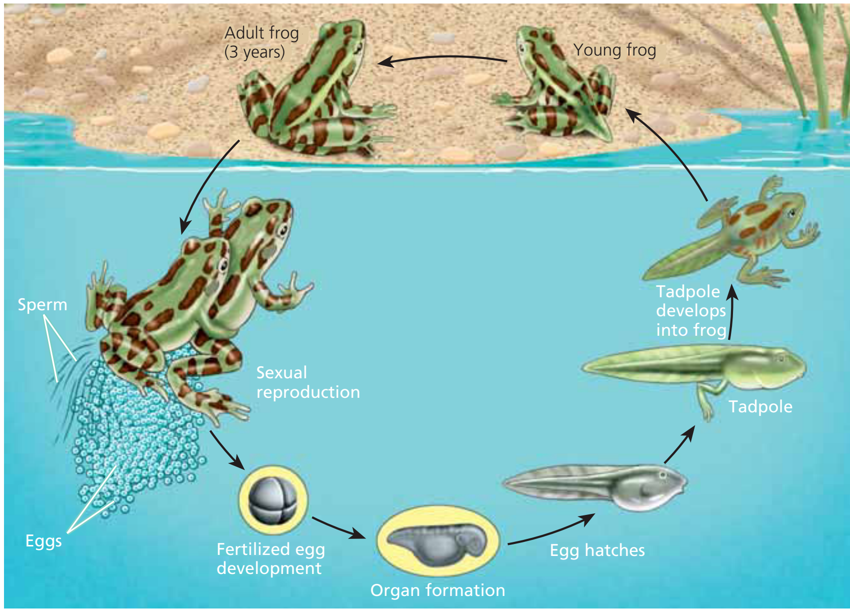


Figure 4-14 *Life cycle of a frog.* Populations of various frog species can decline because of the effects of harmful factors at different points in their life cycle. Such factors include habitat loss, drought, pollution, increased ultraviolet radiation, parasitism, disease, overhunting by humans, and nonnative predators and competitors.

Amphibians were the first vertebrates to set foot on the earth. Historically, they have been better than many other species have been at adapting to environmental changes through evolution. But many amphibian species apparently are having difficulty adapting to some of the rapid environmental changes that have taken place in the air and water and on the land during the past few decades—changes resulting mostly from human activities. Evolution takes time and some amphibians have traits that can make them vulnerable to certain changes in environmental conditions. Frogs, for example, are especially vulnerable to environmental disruption at various points in their life cycle (Figure 4-14).

As tadpoles, frogs live in water and eat plants; as adults, they live mostly on land and eat insects, which can expose them to pesticides. The eggs of frogs have no protective shells to block UV radiation or pollution. As adults, they take in water and air through their thin, permeable skins, which can readily absorb pollutants from water, air, or soil. During their life cycle, frogs and many other amphibian species also seek sunlight, which warms them and helps them to grow and develop, but which also increases their exposure to UV radiation.

Since 1980, populations of hundreds of the world's almost 6,000 amphibian species have been vanishing or declining in almost every part of the world, even in protected wildlife reserves and parks. According to the 2004 Global Amphibian Assessment, about 33% of all known amphibian species (and more than 80% of those in the Caribbean) are threatened with extinction, and populations of 43% of the species are declining.

No single cause has been identified to explain these amphibian declines. However, scientists have identified a number of factors that can affect frogs and other amphibians at various points in their life cycles:

- *Habitat loss and fragmentation,* especially from draining and filling of inland wetlands, deforestation, and urban development
- *Prolonged drought,* which can dry up breeding pools so that few tadpoles survive
- *Pollution,* especially exposure to pesticides, which can make frogs more vulnerable to bacterial, viral, and fungal diseases
- *Increases in UV radiation* caused by reductions in stratospheric ozone during the past few decades, caused by chemicals we have put into the air that have ended up in the stratosphere
- *Parasites* such as flatbed worms, which feed on the amphibian eggs laid in water, apparently have caused an increase in births of amphibians with missing or extra limbs

- *Viral and fungal diseases,* especially the chytrid fungus, which attacks the skin of frogs, apparently reducing their ability to take in water, which leads to death from dehydration. Such diseases spread when adults of many amphibian species congregate in large numbers to breed.
- *Climate change.* A 2005 study found an apparent correlation between global warming and the extinction of about two-thirds of the 110 known species of harlequin frog in tropical forests in Central and South America by creating favorable conditions for the spread of the deadly chytrid fungus to the frogs. But a 2008 study cast doubt on this hypothesis—another example of how science works. Climate change from global warming has also been identified as the primary cause of the extinction of the golden toad in Costa Rica (Figure 4-9).
- *Overhunting,* especially in Asia and France, where frog legs are a delicacy
- *Natural immigration of, or deliberate introduction of, nonnative predators and competitors* (such as certain fish species)

A combination of such factors probably is responsible for the decline or disappearance of most amphibian species.

RESEARCH FRONTIER

Learning more about why amphibians are disappearing and applying this knowledge to other threatened species. See **academic.cengage.com/biology/miller**.

Why should we care if some amphibian species become extinct? Scientists give three reasons. *First,* amphibians are sensitive biological indicators of changes in environmental conditions such as habitat loss and degradation, air and water pollution, exposure to ultraviolet light, and climate change. Their possible extinction suggests that environmental health is deteriorating in parts of the world.

Second, adult amphibians play important ecological roles in biological communities. For example, amphibians eat more insects (including mosquitoes) than do birds. In some habitats, extinction of certain amphibian species could lead to extinction of other species, such as reptiles, birds, aquatic insects, fish, mammals, and other amphibians that feed on them or their larvae.

Third, amphibians are a genetic storehouse of pharmaceutical products waiting to be discovered. Compounds in secretions from amphibian skin have been isolated and used as painkillers and antibiotics and as treatment for burns and heart disease.

The rapidly increasing global extinction of a variety of amphibian species is a warning about the harmful effects of an array of environmental threats to biodiversity. Like canaries in a coal mine, these indicator species are sending us urgent distress signals.

Keystone and Foundation Species Help Determine the Structure and Functions of Their Ecosystems

A keystone is the wedge-shaped stone placed at the top of a stone archway. Remove this stone and the arch collapses. In some communities and ecosystems, ecologists hypothesize that certain species play a similar role. **Keystone species** have a large effect on the types and abundances of other species in an ecosystem.

The effects that keystone species have in their ecosystems is often much larger than their numbers would suggest, and because of their relatively limited numbers, some keystone species are more vulnerable to extinction than others are. As was shown by the near extinction of the American alligator (**Core Case Study**) in the southeastern United States, eliminating a keystone species may dramatically alter the structure and function of a community.

CORE CASE STUDY

Keystone species can play several critical roles in helping to sustain an ecosystem. One such role is *pollination* of flowering plant species by bees, butterflies (Figure 3-A, left, p. 54), hummingbirds, bats, and other species. In addition, *top predator* keystone species feed on and help regulate the populations of other species. Examples are the alligator, wolf, leopard, lion, and some shark species (see Case Study, p. 96).

Ecologist Robert Paine conducted a controlled experiment along the rocky Pacific coast of the U.S. state of Washington that demonstrated the keystone role of the top-predator sea star *Piaster orchaceus* in an intertidal zone community. Paine removed the mussel-eating *Piaster* sea stars from one rocky shoreline community but not from an adjacent community, which served as a control group. Mussels took over and crowded out most other species in the community without the *Piaster* sea stars.

The loss of a keystone species can lead to population crashes and extinctions of other species in a community that depends on it for certain services, as we saw in the **Core Case Study** that opens this chapter. This explains why it so important for scientists to identify and protect keystone species.

CORE CASE STUDY

Another important type of species in some ecosystems is a **foundation species,** which plays a major role in shaping communities by creating and enhancing their habitats in ways that benefit other species. For example, elephants push over, break, or uproot trees, creating forest openings in the grasslands and woodlands of Africa. This promotes the growth of grasses and other forage plants that benefit smaller grazing species such as antelope. It also accelerates nutrient cycling rates.

Beavers are another good example of a foundation species. Acting as "ecological engineers," they build dams in streams to create ponds and other wetlands used by other species. Some bat and bird foundation species help to regenerate deforested areas and spread fruit plants by depositing plant seeds in their droppings.

Keystone and foundation species play similar roles. In general, the major difference between the two types of species is that foundation species help to create habitats and ecosystems. They often do this almost literally by providing the foundation for the ecosystem (as beavers do, for example). On the other hand, keystone species can do this and more. They sometimes play this foundation role (as do American alligators, for example), but they also play an active role in maintaining the ecosystem and keeping it functioning in a way that serves the other species living there. (Recall that the American alligator helps to keep the waters in its habitat clear of invading vegetation for use by other species that need open water.)

RESEARCH FRONTIER

Identifying and protecting keystone and foundation species. See **academic.cengage.com/biology/miller**.

THINKING ABOUT

The American Alligator

CORE CASE STUDY

What species might disappear or suffer sharp population declines if the American alligator (**Core Case Study**) became extinct in subtropical wetland ecosystems?

■ CASE STUDY

Why Should We Protect Sharks?

The world's 370 shark species vary widely in size. The smallest is the dwarf dog shark, about the size of a large goldfish. The largest, the whale shark, can grow to 15 meters (50 feet) long and weigh as much as two full-grown African elephants.

Shark species that feed at or near the tops of food webs (Figure 3-14, p. 63) remove injured and sick animals from the ocean, and thus play an important ecological role. Without the services provided by these *keystone species*, the oceans would be teeming with dead and dying fish.

In addition to their important ecological roles, sharks could save human lives. If we can learn why they almost never get cancer, we could possibly use this information to fight cancer in our own species. Scientists are also studying their highly effective immune system, which allows wounds to heal without becoming infected.

Many people—influenced by movies, popular novels, and widespread media coverage of a fairly small number of shark attacks per year—think of sharks as people-eating monsters. In reality, the three largest species—the whale shark, basking shark, and megamouth shark—are gentle giants. They swim through the water with their mouths open, filtering out and swallowing huge quantities of plankton.

Media coverage of shark attacks greatly distorts the danger from sharks. Every year, members of a few species—mostly great white, bull, tiger, gray reef, lemon, hammerhead, shortfin mako, and blue sharks—injure 60–100 people worldwide. Since 1990, sharks have killed an average of seven people per year. Most attacks involve great white sharks, which feed on sea lions and other marine mammals and sometimes mistake divers and surfers for their usual prey. Compare the risks: poverty prematurely kills about 11 million people a year, tobacco 5 million a year, and air pollution 3 million a year.

For every shark that injures a person, we kill at least 1 million sharks. Sharks are caught mostly for their valuable fins and then thrown back alive into the water, fins removed, to bleed to death or drown because they can no longer swim. The fins are widely used in Asia as a soup ingredient and as a pharmaceutical cure-all. A top (dorsal) fin from a large whale shark can fetch up to $10,000. In high-end restaurants in China, a bowl of shark fin soup can cost $100 or more. Ironically, shark fins have been found to contain dangerously high levels of toxic mercury.

Sharks are also killed for their livers, meat, hides, and jaws, and because we fear them. Some sharks die when they are trapped in nets or lines deployed to catch swordfish, tuna, shrimp, and other species. Sharks are especially vulnerable to overfishing because they grow slowly, mature late, and have only a few offspring per generation. Today, they are among the most vulnerable and least protected animals on earth.

In 2008, The IUCN-World Conservation Union reported that the populations of many large shark species have declined by half since the 1970s. Because of the increased demand for shark fins and meat, eleven of the world's open ocean shark species are considered critically endangered or endangered, and 81 species are threatened with extinction. In response to a public outcry over depletion of some species, the United States and several other countries have banned the hunting of sharks for their fins. But such bans apply only in territorial waters and are difficult to enforce.

Scientists call for banning shark finning in international waters and establishing a network of fully protected marine reserves to help protect coastal shark and other aquatic species from overfishing. Between 1970 and 2005, overfishing of hammerhead, bull, dusky, and other large predatory sharks in the northwest Atlantic for their fins and meat cut their numbers by 99%. In 2007, scientists Charles "Pete" Peterson and Julia Baum reported that this decline may be indirectly decimating the bay scallop fishery along the eastern coast of the United States. With fewer sharks around, populations of rays and skates, which sharks normally feed on, have exploded and are feasting on bay scallops in seagrass beds along the Atlantic coast.

Sharks have been around for more than 400 million years. Sustaining this portion of the earth's biodiversity begins with the knowledge that sharks may not need us, but that we and other species need them.

HOW WOULD YOU VOTE?

Do we have an ethical obligation to protect shark species from premature extinction and to treat them humanely? Cast your vote online at **academic.cengage.com/biology/miller**.

REVISITING The American Alligator and Sustainability

CORE CASE STUDY

The **Core Case Study** of the American alligator at the beginning of this chapter illustrates the power humans have over the environment—the power both to do harm and to make amends. As most American alligators were eliminated from their natural areas in the 1950s, scientists began pointing out the ecological benefits these animals had been providing to their ecosystems (such as building water holes, nesting mounds, and feeding sites for other species). Scientific understanding of these ecological connections led to protection of this species and to its recovery.

In this chapter, we studied the importance of biodiversity, especially the numbers and varieties of species found in different parts of the world (species richness), along with the other forms of biodiversity—functional, ecosystem, and genetic diversity. We also studied the process whereby all species came to be, according to scientific theory of biological evolution through natural selection. Taken together, these two great assets, biodiversity and evolution, represent irreplaceable natural capital. Each depends upon the other and upon whether humans can respect and preserve this natural capital. Finally, we examined the variety of roles played by species in ecosystems.

Ecosystems and the variety of species they contain are functioning examples of the four **scientific principles of sustainability** (see back cover) in action. They depend on solar energy and provide functional biodiversity in the form of energy flow and the chemical cycling of nutrients. In addition, ecosystems sustain biodiversity in all its forms, and population sizes are controlled by interactions among diverse species. In the next chapter, we delve further into this natural regulation of populations and the biodiversity of ecosystems.

All we have yet discovered is but a trifle
in comparison with what lies hid
in the great treasury of nature.

ANTOINE VAN LEEUWENHOEK

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 78. Explain why we should protect the American alligator (**Core Case Study**) from being driven to extinction as a result of our activities. CORE CASE STUDY
2. What are the four major components of **biodiversity (biological diversity)?** What is the importance of biodiversity?
3. What is **biological evolution?** What is **natural selection?** What is a **fossil** and why are fossils important in understanding biological evolution? What is a **mutation** and what role do mutations play in evolution by natural selection? What is an **adaptation (adaptive trait)?** What is **differential reproduction?** How did we become such a powerful species?
4. What are two limits to evolution by natural selection? What are three myths about evolution through natural selection?
5. Describe how geologic processes and climate change can affect natural selection. Describe conditions on the earth that favor the development of life as we know it.
6. What is **speciation?** Distinguish between **geographic isolation** and **reproductive isolation** and explain how they can lead to the formation of a new species. Distinguish between **artificial selection** and **genetic engineering (gene splicing)** and give an example of each. What are some possible social, ethical, and environmental problems with the widespread use of genetic

engineering? What is **extinction?** What is an **endemic species** and why is it vulnerable to extinction? Distinguish between **background extinction** and **mass extinction.**

7. What is **species diversity?** Distinguish between **species richness** and **species evenness** and give an example of each. Describe the **theory of island biogeography (species equilibrium model).** Explain why species-rich ecosystems tend to be productive and sustainable.

8. What is an **ecological niche?** Distinguish between **specialist species** and **generalist species** and give an example of each.

9. Distinguish among **native, nonnative, indicator, keystone,** and **foundation** species and give an example of each type. Explain why birds are excellent indicator species. Why are amphibians vanishing and why should we protect them? Why should we protect shark species from being driven to extinction as a result of our activities? Describe the role of the beaver as a foundation species.

10. Explain how the role of the American alligator in its ecosystem (**Core Case Study**) illustrates the biodiversity **principles of sustainability**?

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concept 4-4B** in order to live a more environmentally sustainable lifestyle.

2. Explain what could happen to the ecosystem where American alligators (**Core Case Study**) live if the alligators went extinct. Name a plant species and an animal species that would be seriously affected, and describe how each might respond to these changes in their environmental conditions.

3. What role does each of the following processes play in helping implement the four **scientific principles of sustainability** (see back cover): **(a)** natural selection, **(b)** speciation, and **(c)** extinction?

4. Describe the major differences between the ecological niches of humans and cockroaches. Are these two species in competition? If so, how do they manage to coexist?

5. How would you experimentally determine whether an organism is a keystone species?

6. Is the human species a keystone species? Explain. If humans were to become extinct, what are three species that might also become extinct and three species whose populations would probably grow?

7. How would you respond to someone who tells you:
   a. that he or she does not believe in biological evolution because it is "just a theory"?
   b. that we should not worry about air pollution because natural selection will enable humans to develop lungs that can detoxify pollutants?

8. How would you respond to someone who says that because extinction is a natural process, we should not worry about the loss of biodiversity when species become prematurely extinct as a result of our activities?

9. Congratulations! You are in charge of the future evolution of life on the earth. What are the three most important things you would do?

10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

Injuries and deaths from shark attacks are highly publicized by the media. However, the risk of injury or death from a shark attack for people going into coastal waters as swimmers, surfers, or divers is extremely small (see Case Study, p. 96). For example, according to the National Safety Council, the Centers for Disease Control and Prevention, and the International Shark Attack File, the estimated lifetime risk of dying from a shark attack in the United States is about 1 in 3,750,000 compared to risks of 1 in 1,130 from drowning, 1 in 218 from a fall, 1 in 84 from a car accident, 1 in 63 from the flu, and 1 in 38 from a hospital infection.

Between 1998 and 2007, the United States had the world's highest percentage of deaths and injuries from unprovoked shark attacks, and the U.S. state of Florida had the country's highest percentage of deaths and injuries from unprovoked shark attacks, as shown by the following data about shark attacks in the world, in the United States, and in Florida.

	World			United States			Florida		
Year	Total Attacks	Fatal Attacks	Non-fatal Attacks	Total Attacks	Fatal Attacks	Non-fatal Attacks	Total Attacks	Fatal Attacks	Non-fatal Attacks
1998	51	6	45	26	1	25	21	1	20
1999	56	4	52	38	0	38	26	0	26
2000	79	11	68	53	1	52	37	1	36
2001	68	4	64	50	3	47	34	1	33
2002	62	3	59	47	0	47	29	0	29
2003	57	4	53	40	1	39	30	0	30
2004	65	7	58	30	2	28	12	0	12
2005	61	4	57	40	1	39	20	1	19
2006	63	4	59	40	0	40	23	0	23
2007	71	1	70	50	0	50	32	0	32

Source: Data from *International Shark Attack File,* Florida Museum of Natural History, University of Florida.

1. What is the average number for each of the nine columns of data—unprovoked shark attacks, deaths, and non-fatal injuries between 1998 and 2007 for the world, the United States, and Florida?

2. What percentage of the world's average annual unprovoked shark attacks between 1998 and 2007 occurred in **(a)** the United States and **(b)** Florida?

2. What percentage of the average annual unprovoked shark attacks in the United States between 1998 and 2007 occurred in Florida?

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 4 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.