CHAPTER 4

Principles of Ecology: How Ecosystems Work

CHAPTER OUTLINE

Never does nature say one thing, and wisdom another.

—Juvenal

Most of us live our lives seemingly apart from nature. We make our homes in cities and towns, surround ourselves with concrete and steel, and drown out the songs of birds with noise. The closest many of us get to nature is a romp with the family dog on the grass in the backyard. A lucky few come in much closer contact with the great outdoors through hiking, camping, canoeing, and kayaking. For many of these people, though, nature is still viewed as something apart from humans—a thing to protect to preserve a few pristine places for people to enjoy.

4.1 Humans and Nature: The Vital Connections

Hard as it may be for many people to accept, human beings are part of the fabric of life. We are a part of nature. We are dependent on the Earth and natural systems in thousands of ways and are an integral part of the cycles of nature. Consider our de-

CRITICAL THINKING

Exercise

The information gained from various fields of science such as ecology is often loosely translated in the public arena. Terms are sometimes misinterpreted. Facts are taken out of context. New findings are given more credence than they deserve, and old, disproved ideas remain in the popular thinking for a long time. As you read this chapter, make a list of terms, ideas, concepts, and facts you encounter that contradict what you thought was true.

pendence first by taking a look around the room in which you are sitting. Everything in that room comes from the Earth or a natural system. The clothes you wear, your morning tea or coffee, and even the cornflakes you ate for breakfast are products of the Earth—the soil, water, air, and plants.

Like all other species, humans depend on the soil, air, water, sun, and a host of living organisms to survive. Each year, in fact, human beings (and other animals) consume enormous quantities of oxygen, which is used in the cells of our bodies to break down food molecules to generate energy. Oxygen is produced by plants and algae. Without these organisms, humans and other animals could not survive. Trees, grasses, and other plants also provide a host of additional free services. For example, plants protect the watersheds near our homes, preventing flooding and erosion. Swamps purify the water in streams and lakes—water many of us drink. Birds help to control insect populations.

Clearly, nature serves us well. Although many of us have isolated ourselves from nature, we still depend on nature in many ways. We have not emancipated ourselves from it at all. We also influence natural cycles, and therefore, as Chapter 1 explained, not only do we depend on nature, the fate of natural systems depends on us.

KEY CONCEPTS

Humans are a part of nature, dependent on natural systems for a variety of economically important resources and ecological services essential to our survival and long-term prosperity.

4.2 Ecology: The Study of Natural Systems

This chapter explores *ecology*, the study of living organisms and the web of relationships that binds all of us together in nature. Professor Garrett Hardin, a world-renowned ecologist, wrote that ecology takes as its domain the entire living world. Ecologists study how organisms interact with one another and how they interact with the *abiotic*, or nonliving, components of the environment (sunlight, for example).

Throughout this chapter, we explore our connections to the living world. We examine the ways in which human systems depend on natural systems and the ways in which humans affect them. One of the goals of this chapter is to help you understand how nature works and how we can work better with nature to create a sustainable future. You will find that a great many of the lessons learned from the study of ecology can be applied to human society. Before we begin our journey, however, let me say a few words about the term *ecology*.

GO GREEN

Check out current efforts to green your campus and become an active participant! If your college or university isn't actively pursuing ways to go green, consider organizing an effort with key student organizations, faculty members, and administrators. Chances are there are plenty of environmentally active faculty and staff that would love to help out.

Ecology is probably one of the most misused words in the English language. Banners proclaim, "Save Our Ecology." Speakers argue that "our ecology is in danger," and others talk about the "ecological movement." These common uses of the word *ecology* are incorrect. Why?

Ecology is a branch of science. It describes and quantifies the web of interactions in the environment. But ecology is not synonymous with the word *environment*. Thus, we can save our ecology department and ecology textbooks, but we cannot save our ecology. Our ecology is not in danger, but our environment is. You cannot join the ecology movement, but you would be a welcome addition to the environmental movement.

KEY CONCEPTS

Ecology is a field of science that seeks to describe relationships between organisms and their chemical and physical environment.

4.3 The Structure of Natural Systems

In order to understand ecology, you must study the structure of natural systems. We begin with the biosphere.

The Biosphere

The science of ecology focuses much of its attention on biological systems, examining their components and interactions. The largest biological system is the **biosphere** (BI-oh-sfere), the skin of life on planet Earth. As shown in **FIGURE 4-1**, the biosphere forms at the intersection of air, water, and land. In fact, all living organisms consist of components derived from these three realms. The carbon atoms in body proteins, for example, come from carbon dioxide in the atmosphere. Carbon dioxide is captured by plants and made into food molecules by a process known as **photosynthesis.** Animals eat plants; the food molecules then become the building blocks of proteins and other important molecules in animals. The minerals in the bones of animals

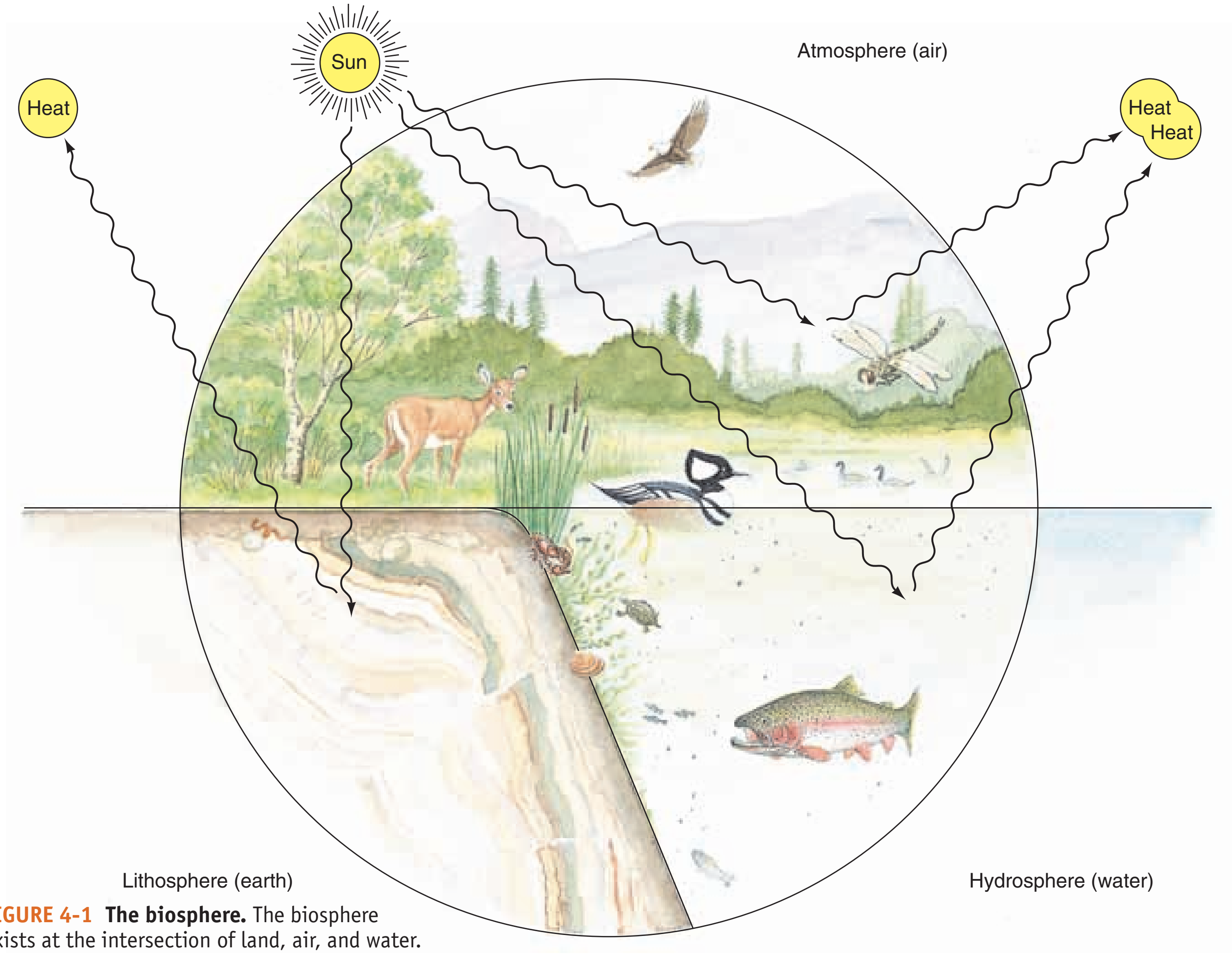


FIGURE 4-1 The biosphere. The biosphere exists at the intersection of land, air, and water. Organisms derive essential minerals and other substances from these three spheres.

come from the soil, again through plants. Water comes directly from streams and lakes and plant matter.

The biosphere extends from the bottom of the ocean, approximately 11,000 meters (36,000 feet) below the surface, to the tops of the highest mountains, about 9,000 meters (30,000 feet) above sea level. Although that may seem like a long way, it's really not. In fact, if the Earth were the size of an apple, the biosphere would be about the thickness of its skin. Although life exists throughout the biosphere, it is rare at the extremes, where conditions for survival are less than optimum. Most living things are concentrated in a narrow band extending from less than 200 meters (600 feet) below the surface of the ocean to about 6,000 meters (20,000 feet) above sea level.

The biosphere is a **closed system**, much like a sealed terrarium. By definition, a closed system receives no materials from the outside. The only outside contribution is sunlight, which is vital to the health and well-being of virtually all life.

Sunlight powers almost all life on the planet. Even the energy released by the combustion of coal, oil, and natural gas (which we use to power our homes and factories) comes from sunlight that fell on the Earth several hundred million years ago.

Because the Earth is a closed system, all materials necessary for life must be recycled. The carbon dioxide you exhale, for instance, may be used by a rice plant during photosynthesis next month in Indonesia. Those carbon dioxide molecules will be incorporated into carbohydrate produced by the plant and stored in the seed. Consumed by an Indonesian boy, the carbohydrate will be broken back down during cellular energy production. The carbon dioxide molecules are released into the atmosphere. Without this and dozens of other recycling processes, all life on the planet would grind to a halt. Protecting the environment, then, helps to protect global recycling systems on which we all depend.

KEY CONCEPTS

The biosphere is an enormous biological system, spanning the entire planet. The materials within this closed system are recycled over and over in order for life to be sustained. The only outside contribution to the biosphere is sunlight, which provides energy for all living things.

Biomes and Aquatic Life Zones

The biosphere consists of terrestrial and aquatic systems. Viewed from outer space, the Earth—the terrestrial portion of the biosphere—resembles a giant jigsaw puzzle, consisting of large landmasses among vast expanses of ocean. The land-

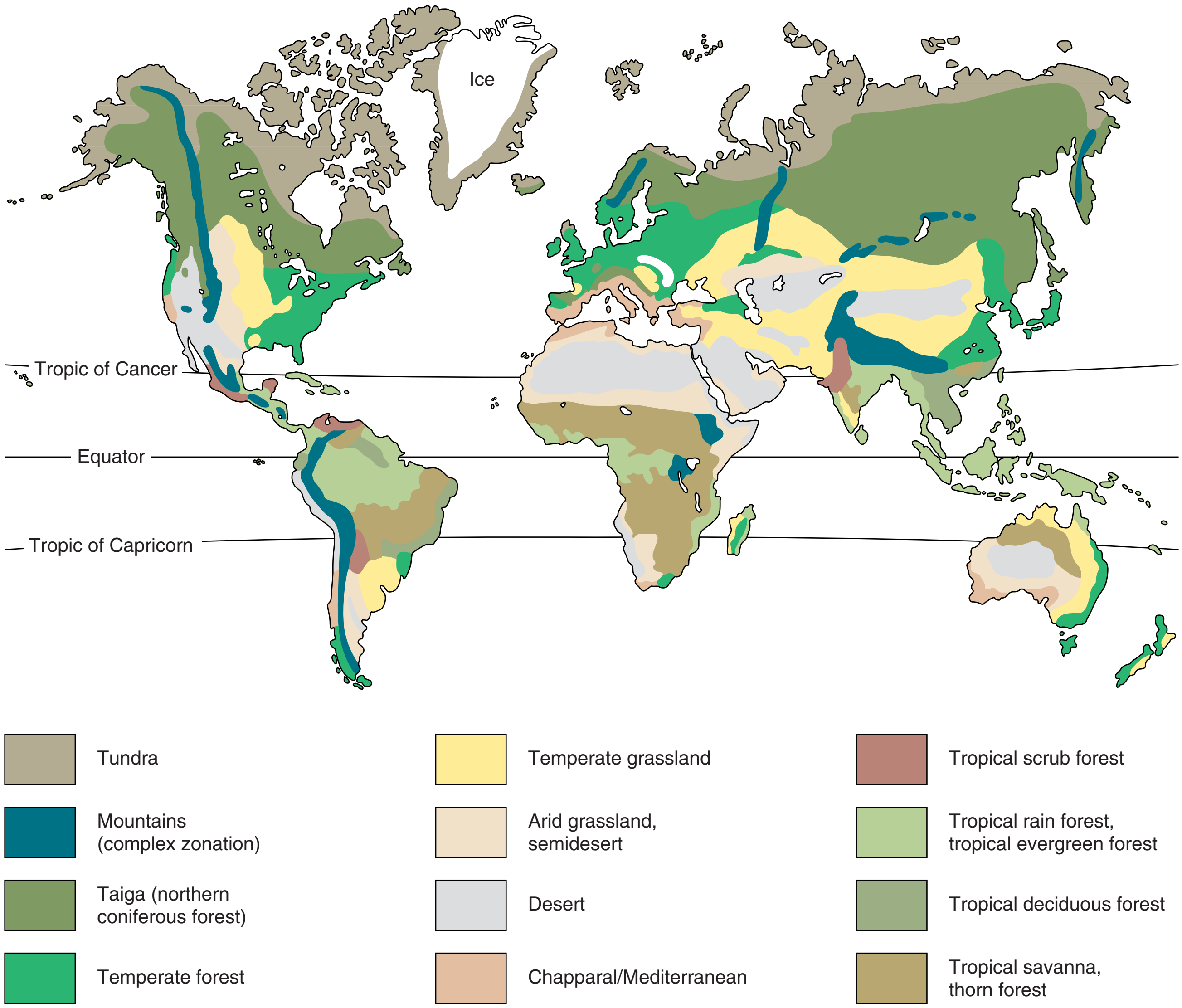


FIGURE 4-2 Biomes. This map shows the world's major biomes.

masses, or continents, can be divided into fairly large regions called *biomes* (**FIGURE 4-2**). A **biome** is a terrestrial portion of the biosphere characterized by a distinct climate and a particular assemblage of plants and animals adapted to it.[1] Chapter 5 describes the biomes in detail. This section provides an overview.

In a biome, abiotic conditions—such as soil type, temperature, and rainfall—determine the plant communities that can survive. These, in turn, determine which animals can subsist. As illustrated in Figure 4-2, the North American continent contains seven major biomes, five of which are discussed here. Starting in the north is the **tundra** (TON-dra), a region of long, cold winters and rather short growing seasons (**FIGURE 4-3a**). The rolling terrain of the tundra supports grasses, mosses, lichens, wolves, musk oxen, and other animals adapted to the bitter winter cold. Trees cannot grow on the tundra because of the short growing season and because the subsoil (called *permafrost*) remains frozen year round, preventing the deep root growth necessary for trees.

Immediately south of the tundra lies the **taiga** (TIE-ga), also known as the **northern coniferous** or **boreal forest.** The taiga's milder climate and longer growing season result in a greater diversity and abundance of plant and animal life than exists on the tundra. Evergreen trees, bears, wolverines, and moose are characteristic species (**FIGURE 4-3b**).

East of the Mississippi River lies the **temperate deciduous forest biome**, characterized by an even warmer climate and more abundant rainfall (**FIGURE 4-3c**). Broad-leaved trees make their home in this biome. Opossums, black bears, squirrels, and foxes are characteristic animal species.

West of the Mississippi lies the **grassland biome** (**FIGURE 4-3d**). Inadequate rainfall and periodic drought prevent trees from growing on the grasslands, except near rivers, streams, and human habitation. Over the years, deep-rooted grasses have evolved on the plains. These grasses can withstand fire, drought, and grazing even in arid grasslands. Coyotes, hawks, and voles are characteristic animal species.

[1]Although each biome has its specific climate, there can be considerable climatic variation within a given biome.

(a)

(b)

(c)

(d)

(e)

FIGURE 4-3 **North America's five major biomes. (a)** Tundra, **(b)** taiga, **(c)** temperate deciduous forest, **(d)** grassland, and **(e)** desert.

In the Southwest, where even less rain falls, is the **desert biome** (FIGURE 4-3e). In contrast to what many people think, the desert often contains a rich assortment of plants and animals uniquely adapted to aridity and heat. Cacti, mesquite trees, rattlesnakes, and a variety of lizards all make their home in this seemingly inhospitable environment. The scorching hot deserts of Saudi Arabia receive less moisture than the desert around Tucson and therefore contain far fewer plants and animals.

The oceans can also be divided into distinct zones, known as **aquatic life zones**. The aquatic equivalent of biomes, each of these regions has a distinct environment and characteristic plant and animal life adapted to conditions of the zone. Both freshwater and saltwater (marine) systems exist. Freshwater systems include lakes, rivers, ponds, and marshes. The four major marine aquatic life zones are coral reefs, estuaries (the mouths of rivers, where fresh and salt water mix), the deep ocean, and the continental shelf, all of which are discussed in the next chapter.

Humans inhabit all biomes on Earth but are concentrated in those in which conditions are mildest and most conducive to growing food. Within many biomes is a wide assortment of natural resources such as minerals and fuel. Although they are vital to our economies and well-being, these resources are but a fraction of the benefit we gain from the biome. Plants and animals, for example, provide food and great enjoyment to many. Microorganisms in the soils of the biome detoxify wastes and recycle nutrients, keeping the soil rich and productive. The soil itself serves as a growing medium for all plants—crops as well as forests. Besides providing timber, trees provide oxygen, remove air pollutants, and protect the soil from erosion, thus reducing sediment pollution in surface waters. Vegetation also reduces flooding.

KEY CONCEPTS

The biosphere consists of distinct regions called *biomes* and aquatic life zones, each with its own chemical and physical conditions and unique assemblage of organisms. Humans inhabit all biomes, but are most prevalent in those with the mildest climates.

What Is an Ecosystem?

The biosphere is a chemical, physical, and biological system that encompasses the entire surface of the planet. Therefore, the biosphere is often referred to as a global **ecological system**, or **ecosystem**. If the biosphere is a global ecosystem, biomes are regional ecosystems. For the sake of convenience, ecologists often limit their studies to smaller portions of a biome—individual forests, ponds, or meadows. All of these ecosystems, no matter how big or small, consist of two components: the living or **biotic** components and the nonliving or **abiotic** components. Numerous interactions exist among these various components.

KEY CONCEPTS

Ecosystems are biological systems consisting of organisms and their environment.

Abiotic Components of Ecosystems and the Range of Tolerance The abiotic components of an ecosystem are the physical and chemical factors necessary for life—sunlight, precipitation, temperature, and nutrients. In most ecosystems, the abiotic conditions vary during the day and often shift from one season to the next. To live in most ecosystems, then, organisms must be able to survive a range of conditions. The range of conditions to which an organism is adapted is called its **range of tolerance**. As FIGURE 4-4 shows, organisms do best in the **optimum range**. Outside of that are the **zones of physiological stress**, where survival and reproduction are possible but not optimal. Outside of these zones are the **zones of intolerance**, where life for that organism is implausible. As a rule, organisms that have a wide range of tolerance are

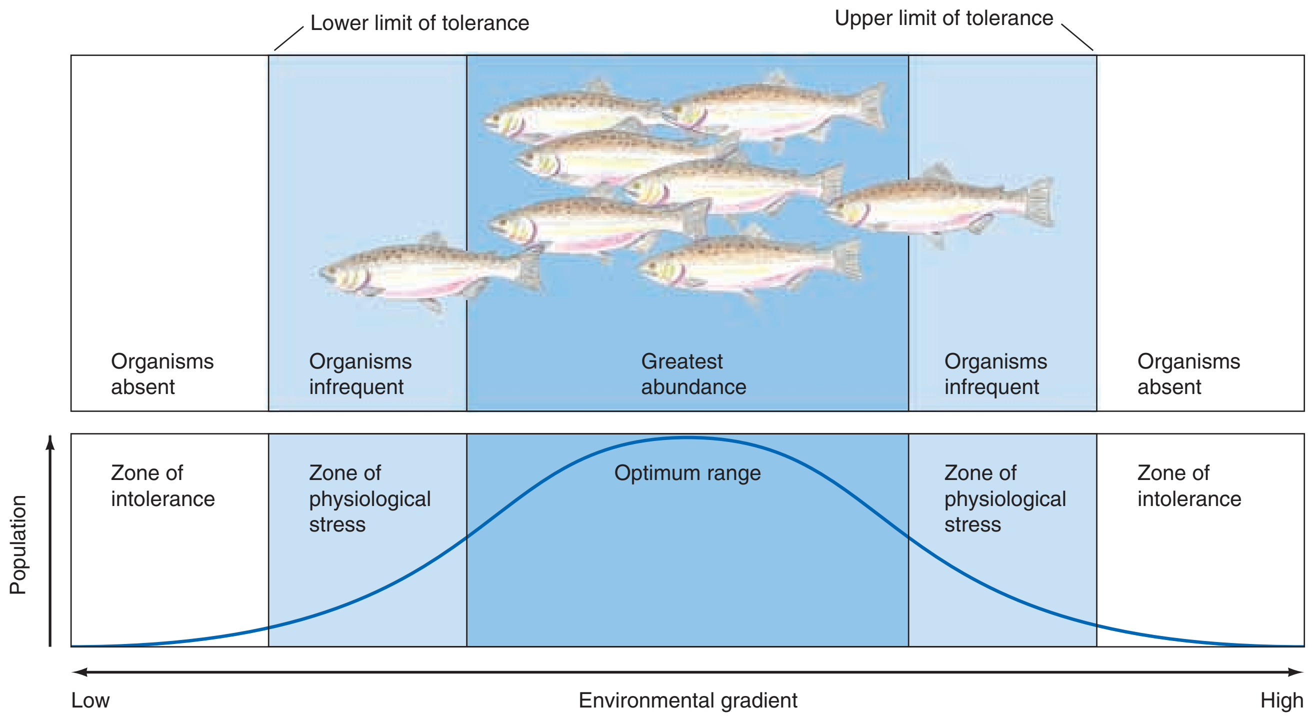


FIGURE 4-4 Range of tolerance. Organisms can live within a range of conditions, called the range of tolerance, but they thrive in the optimum range.

(a)

(b)

FIGURE 4-5 Upsetting the ecological balance. (a) Dams like the mighty Glen Canyon Dam in Arizona not only inundate upstream areas, they often change the water temperature in the downstream section. **(b)** The cool water flowing out of the bottom of the reservoir created by Glen Canyon Dam has endangered the razorback sucker and several other native fish species.

more widely distributed than organisms with a narrow range of tolerance.

Many examples of the range of tolerance can be given. Think of your own tolerance for temperature. Most people are comfortable around 23°C (70°F). When the temperature becomes much warmer, you enter the zone of physiological stress. If it increases even more, death occurs if you can't find a way to cool yourself down. This is the zone of intolerance. The same occurs at the lower end of the temperature scale.

It is important to note that the tolerance of any given species for an environmental factor may vary with the age of the organism. Newly hatched salmon, for instance, may be much more vulnerable to pollutants in the water than adult salmon are. The tolerance of individuals in any population also varies. Thus, some humans are more tolerant than others to heat or cold.

Humans often alter the abiotic components of their environment. Dams, for example, create lakes in streambeds, altering water temperature and water flow, with devastating effects on native fish populations. Dams also seriously alter downstream conditions. In the Colorado River, for instance, native razorback suckers and other species that once thrived in the warm waters of the river are now **endangered species** (in danger of extinction) because of the large dams that release extremely cold water from the bottom of the reservoir (FIGURE 4-5a). This water is too cold for the sucker and other natives (FIGURE 4-5b). (The Point/Counterpoint in this chapter gives two opposing views on human-caused extinction.)

Natural events can also alter the biotic and abiotic conditions of the environment. Floods, tropical storms, and volcanic eruptions all change conditions for varying periods, with sometimes dramatic effects on native species.

KEY CONCEPTS

Organisms thrive within a range of abiotic conditions; altering those conditions can have severe consequences and can even cause extinction.

Limiting Factors Although species are sensitive to all of the abiotic factors in their environment, the one factor that is in short supply, called a **limiting factor**, tends to regulate population size. In freshwater lakes and rivers, dissolved phosphate is a limiting factor. Phosphate is needed by plants and algae for growth, but phosphate concentrations are naturally low. As a result, plant and algal growth is held in check. When phosphate is added to a body of water—say, by detergents released in the effluent of a sewage treatment plant—plants and algae proliferate. Algae often form dense surface mats, blocking sunlight (FIGURE 4-6).

Plants that are rooted on the bottom of the water body may perish for lack of sunlight. Because these plants produce oxygen, their demise often causes oxygen levels in the deeper waters to decline, killing fish and other aquatic organisms. On land, precipitation tends to be the limiting factor. At any

FIGURE 4-6 Algal bloom. This pond is choked with algae due to the abundance of plant nutrients from human sources.

given temperature, the more moisture that falls, the richer the plant and animal life.

KEY CONCEPTS

Organisms require many different abiotic factors to survive, but one factor—*the limiting factor*—tends to be critical to survival and growth of a population. Altering concentrations of limiting factors can result in dramatic fluctuations in populations.

Biotic Components Ecosystems consist of numerous organisms, including bacteria, plants, fungi, and animals. These are the biotic components of the ecosystem. Organisms of the same species within a biome or aquatic life zone usually occupy a specific region. This group of organisms is called a **population.** In any given ecosystem, populations of different organisms exist together in an interdependent **biological community**.

All organisms in a community, including humans, are part of the web of life. Organisms interact in many ways. Some organisms prey on others. Others are preyed upon. Still others compete with fellow members of the community of life.

KEY CONCEPTS

Organisms are the biotic components of ecosystems; they form an interdependent community of life.

Niche and Competition If asked to give a brief description of yourself, you would probably begin by describing the place where you live. You might discuss the work you do, the friends you have, and other important relationships that describe your place in human society. Now that you're discovering your part in nature, you may even describe your place in the community of life.

A biologist would do much the same when describing an organism. He or she would start with a description of the place where an organism lives—that is, its **habitat.** Next, he or she would describe how the organism fits into the ecosystem, its **ecological niche**, or simply **niche.** An organism's niche consists of its relationships with its environment—both the abiotic and biotic components. This niche includes what an organism eats, what eats it, its range of tolerance for various environmental factors, and other important elements. The niche of an organism is its functional role compared with the habitat, which is its "address."

Organisms in a community occupy the same habitat, but most of them have quite different niches, a phenomenon that minimizes competition. The fact that organisms occupy separate niches provides for a wider use of an ecosystem's resources, especially food.

Niches do overlap somewhat. For example, two species may feed on some of the same foods. Coyotes and foxes, for example, both feed on rabbits and mice. Coyotes also feed on larger prey, however—even deer. Foxes tend to feed on smaller prey, including reptiles and amphibians.

The more two species' niches overlap, the more they compete. When niches overlap considerably, competition becomes intense, and one species usually suffers. If two species occupy identical niches, competition will eliminate one of them. As a result, two species cannot occupy the same niche for long. This rule is called the **competitive exclusion principle.**

The concept of the niche is very important to the sustainable management of natural resources. For example, successful control of an insect pest on crops is best achieved through an understanding of the species' niche. An analysis of an insect's niche might show that certain birds or insects feed on the pest. By encouraging these beneficial species—say, by providing trees for the birds—farmers can reduce pest populations naturally. They could also save enormous sums of money on chemical pesticides and help protect the environment.

KEY CONCEPTS

Competition occurs between species occupying the same habitat if their niches overlap; although competition is a naturally occurring process, natural systems have evolved to minimize it.

Humans: Competitors Extraordinaire Humans, like other organisms, compete with one another for a variety of resources. People also compete with the many other species that share this planet with us. For example, we compete with sea otters and seals over salmon. When we graze a cow on a pasture, our livestock compete with woodchucks and rabbits for food.

The competition between people and other species is fairly lopsided. As noted in Chapter 3, humans possess a marked advantage over most other species. This edge on the competition stems primarily from our technological prowess—high-powered rifles, bulldozers, and chain saws being three examples. Fishing nets and sonar give commercial fishers a marked advantage over their two major competitors, seals and sea otters.

As the human population grows, as our demand for food and resources climbs, and as our technological prowess increases, our competitive advantage will only increase, but the effect may not be advantageous to human civilization in the long run. Already, commercial overfishing has depleted dozens of the world's fisheries (Figure 2-6). Many other fisheries are now in danger, as noted in Chapter 2. Overfishing has had a ripple effect on other species, reducing populations of seals and other fish-eating animals.

On every continent and in every nation, humans are outcompeting other species. According to various estimates, 40 to 100 species become extinct every day, largely because of tropical deforestation. Unless we do something, hundreds of thousands of species will become extinct in the next decade. Many scientists warn that none of us will be immune to the impacts of such widespread biological impoverishment. Cutting down the rain forests, for example, could alter global climate. Why? Rain forests absorb massive amounts of carbon dioxide and thus help control atmospheric levels of this important greenhouse gas. As forests are destroyed, carbon dioxide levels increase, and the Earth's atmosphere could become warmer (Chapter 20). We could feel the effect in higher utility bills to cool our homes because

POINT Controversy over Extinction

Humans Are Accelerating Extinction

David M. Armstrong
Dr. David M. Armstrong is a mammologist who taught environmental biology at the University of Colorado at Boulder and has written several books on mammals and ecology of the Rocky Mountain region.

Evolution is the process of change in gene pools through time. When one gene pool becomes reproductively independent, a new species has formed. Such speciation generates species; extinction takes them away. Simply put, extinction is a failure to adapt to change, the termination of a gene pool, the end of an evolutionary line.

Extinction is a natural process. Most species that ever lived are now extinct. The 3 to 30 million species on Earth today are no more than 1 to 10% of the species that have evolved since life began about 3.5 billion years ago. So why are thoughtful people concerned about endangered species? History makes it clear that, given enough time, each species will become extinct.

The concern is that today the natural process of extinction proceeds at an unnatural rate. Let us estimate by how much human activity has accelerated rates of extinction. The average life span of species is 1 to 10 million years. Assume (to be conservative) that the average longevity of species of higher vertebrates is 1 million years. In round numbers, there are 13,000 species of birds and mammals. So, on average, one species ought to go extinct each century. However, between 1,600 and 2,000, at least 36 species of mammals and 94 species of birds became extinct—32 species per year, or 32 times the natural rate.

What does it mean to increase a rate by 32 times? Exceed the 55 mph speed limit by 32-fold, and you are moving 1,760 miles per hour, over twice the speed of sound. The difference between natural rates of extinction and present, human-influenced rates is analogous to the difference between a casual drive and Mach 2! Is that a problem? You decide: Concern is a moral construct, not a scientific one.

Several human activities have contributed—mostly inadvertently—to accelerating rates of extinction. The dodo and the passenger pigeon were extinguished by overhunting. Wolves and grizzly bears were exterminated over much of their ranges as threats to livestock. The black-footed ferret was driven to the verge of extinction because prairie dogs, its staple food, were poisoned as an agricultural pest. The smallpox virus was exterminated in the "wild" (but survives in a half dozen laboratories). This is the closest that humans have come to deliberate elimination of an organism, and note that thoughtful scientists with the power to destroy smallpox chose not to do so, electing instead to manage it with care.

Habitat change is the most important cause of endangerment and extinction. Clearing forests for agriculture has decimated the lemurs of Madagascar. Pesticides led to the decline of the peregrine falcon. Introducing exotic species (like goats on the Galapagos and mongooses in Hawaii) displaces native animals and plants. Developing the Amazon Basin is a habitat alteration, and a cause of extinction, on an unprecedented scale.

Many urge saving species for their aesthetic value. Whooping cranes are beautiful, and part of their beauty is that they are products of a marvelous evolutionary process. Most concern about accelerated extinction, however, stresses economic value. A tiny fraction of seed plants are used commercially. An obscure plant like jojoba eventually could be a source of oil more reliable than the Middle East. Wild grasses have yielded genes that have improved disease resistance in wheat. Some animals like musk ox, kudu, and whales could contribute protein to our diet. Species may have medical value; penicillin, after all, was once an obscure mold on citrus fruit. Some sensitive species are monitors of environmental quality, and the presence of healthy populations of many species may promote greater stability or resilience of ecosystems. Naturalist Aldo Leopold noted that humans have a way of "tinkering" with the ecosphere. But he suggested that the first rule of tinkering ought to be that one never throws away any of the parts.

"Extinction is forever" and impoverishes both ecosystems and the potential richness of human life. Borrowing again from Aldo Leopold, I believe our concern about unnaturally rapid extinction is part of a "right relationship" between people and the landscapes that nurture and inspire them.

Biologist Sir Julian Huxley noted that "we humans find ourselves, for better or worse, business agents for the cosmic process of evolution." We hold power over the future of the biosphere, the power to destroy or preserve. German philosopher Georg Hegel noted that freedom implies responsibility. I agree. The power to destroy species implies a responsibility to preserve them. The question of human-accelerated extinction boils down to a simple ethical question, "Does posterity matter?" Some of us have ethics that are human centered. We ask simply, "Do my children deserve a life as rich, with as much opportunity, as mine?" If they do, then we have the responsibility to choose restraint. (Perhaps my life has been rich enough without the dodo, but I am reluctant to make that judgment for future generations.)

COUNTERPOINT

Extinction Is the Course of Nature

Norman D. Levine
Norman D. Levine was a professor emeritus at the College of Veterinary Medicine and Agricultural Experiment Station, University of Illinois at Urbana. His research interests included parasitology, protozoology, and human ecology. This article is provided by the American Institute of Biological Sciences (© 1989).

Evolution is the formation of new species from preexisting ones by a process of adaptation to the environment. Evolution began long ago and is still going on. During evolution those species better adapted to the environment replaced the less well-adapted species. It is this process, repeated year after year for millennia, that has produced the present mixture of wild species. Perhaps 95% of the species that once existed no longer exist.

Human activities have eliminated many wild species. The dodo is gone, and so is the passenger pigeon. The whooping crane, the California condor, and many other species are on the way out. The bison is still with us because it is protected, and small herds are raised in semicaptivity. The Pacific salmon remains because we provide fish ladders around our dams so it can reach its breeding places. The mountain goat survives because it lives in inaccessible places. But some thousands of other animal species, to say nothing of plants, are extinct, or soon will be.

Some nature lovers weep at this passing and collect money to save species. They make lists of animals and plants that are in danger of extinction and sponsor legislation to save them.

I don't. What the species preservers are trying to do is stop the clock. It cannot and should not be done. Extinction is an inevitable fact of evolution, and it is needed for progress. New species continually arise, and they are better adapted to their environment than those that have died out.

Extinction comes from failure to adapt to a changing environment. The passenger pigeon did not disappear because of hunting alone, but because its food trees were destroyed by land clearing and farming. The prairie chicken cannot find enough of the proper food and nesting places in the cultivated fields that once were prairies.

And you cannot necessarily introduce a new species, even by breeding it in tremendous numbers and putting it out into the wild. Thousands of pheasants were bred and set out year after year in southern Illinois, but in the spring of each year there were none left. Another bird, the capercaillie, is a fine, large game bird in Scandinavia, but every attempt to introduce it into the United States has failed. An introduced species cannot survive unless it is preadapted to its new environment.

A few introduced species are preadapted, and some make spectacular gains. The United States has received the English sparrow, the starling, and the house mouse from Europe, and also the gypsy moth, the European corn borer, the Mediterranean fruit fly, and the Japanese beetle. The United States gave Europe the gray squirrel and the muskrat, among others. The rabbit took over in Australia, at least for a time.

The rabbit and the squirrel were successful on new continents because their requirements are not as narrow as those of other species that failed. Today, adjustment to human-made environments may be just as difficult as adjustment to new continents. The rabbit and the squirrel have succeeded in adjusting to the backyard habitat, but most wild animals have disappeared.

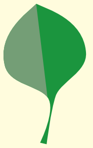
Human-made environments are artificial. People replace mixed grasses, shrubs, and trees with rows of clean-cultivated corn, soybeans, wheat, oats, or alfalfa. Variety has turned into uniform monotony, and the number of species of small vertebrates and invertebrates that can find the proper food to survive has become markedly reduced. But some species have multiplied in these environments and have assumed economic importance; the European corn borer in this country is an example.

Would it improve Earth if even half of the species that have died out were to return? A few starving, shipwrecked sailors might be better off if the dodo were to return, but I would not be. The smallpox virus has been eliminated, except for a few strains in medical laboratories. Should it be brought back? Should we bring panthers back into the eastern states? Think of all the horses that the automobile and tractors have replaced, and of all the streets and roads that have been paved and the wild animals and plants killed as a consequence. Before people arrived in America about 10,000 years ago, the animal–plant situation was quite different. What should we do? Should we all commit suicide?

Evolution exists, and it goes on continually. People are here because of it, but people may be replaced someday. It is neither possible nor desirable to stop it, and that is what we are trying to do when we try to preserve species on their way out. It can be done, I think, but should we do it to them all? Or to just a few, as we are doing now?

Critical Thinking Questions

1. Summarize and critically analyze the key points of both authors. Do you see any flaws in their reasoning?
2. Which viewpoint do you adhere to? Why?



You can link to web sites that represent both sides through Point/Counterpoint: Furthering the Debate at this book's internet site, http://environment.jbpub.com/9e/. Evaluate each side's argument more fully and clarify your own opinion.

of noticeably hotter summers. If predictions come true, we could face much higher food costs as hotter summers reduce crop production. If conditions became bad enough, massive food shortages could occur. Although all this human intrusion is rather depressing, there is hope. We can find ways of coexisting with nature. Understanding how natural systems operate and patterning human systems after sustainable natural systems could help us redesign our infrastructure. See **Spotlight on Sustainable Development 4-1** for an example.

KEY CONCEPTS

Humans are a major competitive force in nature. Our advanced technologies and massive population size permit us to outcompete many species. Destroying other species through competition, however, can be disadvantageous in the long run.

>> SPOTLIGHT ON SUSTAINABLE DEVELOPMENT

4-1 Sustainable Sewage Treatment: Mimicking Nature

Residents of eastern Mexico City produce more than 300 tons of feces every day, much of which is deposited on city streets, vacant lots, and alleys. The feces dry and are often pulverized by cars and trucks. They soon become entrained into the city's dust, creating a monumental health hazard all too common in many poor countries.

Since the advent of cities and towns, dealing with human waste has proved to be a huge challenge. Even in the rich, industrialized countries of the world, modern waste treatment practices leave something to be desired. The liquid waste is chemically treated and dumped into streams and lakes in most cases. The solid material or sludge that remains after treatment is trucked off to landfills.

Traditional waste treatment methods not only pollute our environment, they also waste valuable nutrients, which come from the foods we eat and ultimately the soil on which crops are grown. In nature, plant and animal waste is returned to the soil, where it nourishes new plant life.

Over the years, scientists and others have sought more environmentally compatible—and sustainable—ways of dealing with human waste. Biologist John Todd has led this effort through the invention of waste disposal systems that mimic nature's ways. Todd designed and built his first solar-powered sewage treatment plant at Sugarbush ski resort in Vermont. In this system, known as an Eco Machine, raw sewage enters a solar-heated greenhouse and then flows into cylinders, where naturally occurring bacteria convert the ammonia in the sewage into nitrate, a plant nutrient. The effluent then enters special channels where algae consume the nitrates. The algae are part of an artificial ecosystem containing freshwater shrimp (that feed on algae) and fish (that feed on the shrimp). Snails in the system consume the sludge (organic wastes that fall to the bottom) and also serve as food for fish.

At the far end of the greenhouse is a small marsh containing organisms that remove additional impurities before the water is released into a nearby stream (**FIGURE 1**). In this artificial marsh are many plants that absorb toxic substances.

In Providence, Rhode Island, Todd installed a much larger system that handles up to 16,000 gallons of raw sewage per day flowing through a greenhouse containing 1,200 aquariums, which house a variety of organisms to purify the water. This system, which costs one-third as much as an equivalent sewage treatment plant, has negligible environmental impact. To date, Todd's company, which is now operated by his son, has installed dozens of systems in 11 countries. To learn more you can log on to Todd's website, www.toddecological.com.

Another pioneer in ecologically sound waste disposal is environmental engineer Bill Wolverton. In the mid-1970s, while working at NASA, Wolverton began experiments to purify wastewater from NASA facilities using lagoons filled with prolific, nutrient-hungry water hyacinths, which have be-

FIGURE 1 Proponents of this new technology point out that malfunctions at conventional plants can be serious and sometimes require the evacuation of nearby residents to avoid poisonous chlorine gas emitted from them. A malfunction in a solar-aquatic plant may kill off some organisms, but it poses no threat to people.

4.4 Ecosystem Function

Life on land and in the Earth's waters is possible principally because of the existence of the **producers**, organisms such as the algae and plants. These organisms absorb sunlight and use its energy to synthesize organic foodstuffs from atmospheric carbon dioxide and water via photosynthesis. These organic molecules are used by the producers themselves, but they also provide nourishment for all the other organisms. Producers, therefore, form the foundation of the living world.

Another large group of organisms is the **consumers**. Ecologists place consumers into four general categories, depending on the type of food they eat. Some, such as deer, elk, and cattle, feed directly on plants and are called **herbivores** (ERB-ah-voors). Others, such as wolves, feed on

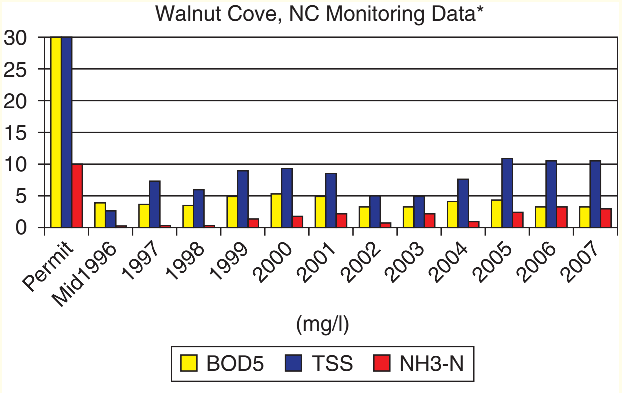
come a "pest" in lakes, streams, and rivers in the southern United States. One system he designed for a 4,000-person NASA facility in Mississippi has saved the agency millions of dollars in sewage fees. Since he began, Wolverton has designed more than a hundred systems in the southern United States. The effectiveness of these systems is illustrated in Figure 2. This graph shows permitted discharges of three pollutants from a conventional sewage treatment plant and levels achieved at a Walnut Cove wastewater treatment facility, designed by Wolverton (**FIGURE 2**).

Researchers are also experimenting with smaller constructed wetlands for biological treatment that we can use in our own backyards. Many are designed so waste water percolates through a bed of gravel under a layer of soil and plants, and thus, there is no way sewage could reach the surface.

Another pioneer in biological waste treatment is Tom Watson, who lives in New Mexico. Watson specializes in household waste treatment centers using inexpensive plastic infiltrators in a pumice bed (**FIGURE 3**). Plants growing in the overlying soil send their roots into pumice, where they feed on water and nutrients from household waste, including toilet water. Bacteria in the pumice decompose organic matter, releasing nutrients for plants.

Biological treatment systems have pros and cons. Those being built by John Todd can operate in virtually any climate. These systems can also be scaled up to any size simply by adding more greenhouses. Watson's systems and constructed wetlands can also function well in a variety of climates, but because they're not protected from the weather, they may have problems in extremely cold climates.

Biological treatment systems, both large and small, are well suited to developing countries because they offer a low-cost option for treating waste. In fact, some developing nations are currently considering installing biological systems to upgrade existing facilities. They're finding that the necessary upgrades can be made at moderate cost. Moreover, the facilities do not require as much management or use as



*Data compiled from Walnut Cove wastewater treatment monitoring data.

FIGURE 2 Graph of pollutants released from a conventional water treatment facility (Permit) and Walnut Cove wastewater treatment. [BODS is biological oxygen demand, a measure of organic waste. TSS is suspended solids, and NH_3-N is nitrogen in the form of ammonia.]

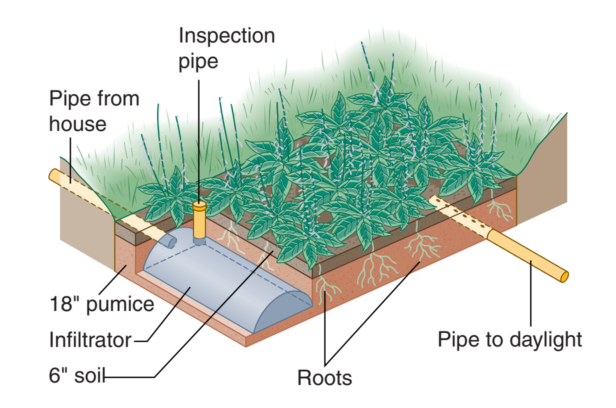


FIGURE 3 **The Watson Wick filter.** In this simple, effective set up waste water enters the pumice bed, where bacteria go to work on waste. Plant roots absorb nutrients and water. Water coming out of the system is relatively free of nutrients. Tests so far have shown them to be more effective than conventional sewage treatment methods.

much energy as conventional systems. They even produce cleaner treated water than their high-tech counterparts—and at a lower cost.

One concern is that in large biological treatment facilities plants may absorb heavy metals such as mercury and lead, which would need to be disposed of in a way that was safe. Todd's colleague, Alan Liss, notes, "It's better to have a small amount of highly toxic plants than a huge amount of moderately toxic sludge." Eliminating such wastes from the waste stream through preventive measures would easily solve this problem.

Larger biological systems such as those being built by John Todd and Bill Wolverton require a level of biological knowledge that few sewage treatment engineers have. They represent a radically different approach for society, even though natural systems have been purifying water for millennia. This appearance of being different makes it difficult to convince city officials to give them a try when they know that existing technology will do the job. Some facilities produce enormous amounts of plant waste, sometimes containing hazardous substances including heavy metals that must be safely disposed of.

Despite their drawbacks, biological systems that mimic nature can be adapted for most or all situations, and their use will undoubtedly rise in the years to come as cities and towns look for more sustainable ways of treating waste.

herbivores and other animals and are known as **carnivores** (CAR-neh-voors). Humans and a great many other animal species subsist on a mixed diet of plants and animals and are known as **omnivores** (OM- neh-voors). Another group feeds on animal waste or the remains of plants and animals and are called **detritivores** (dee-TREH-teh-voors) or **decomposers**. This group includes many bacteria, fungi, and insects.

KEY CONCEPTS

Photosynthetic organisms such as plants and algae produce food within ecosystems. Their well-being is essential to the survival and well-being of all other species.

Food Chains and Food Webs

Biological communities consist of numerous food chains. A **food chain** is a series of organisms, each one feeding on the organism preceding it (FIGURE 4-7). All organisms in the community are members of one or more food chains.

Biologists recognize two general types of food chains: grazer and decomposer. **Grazer food chains** begin with plants and algae. These organisms are consumed by herbivores, or grazers. Herbivores, in turn, may be eaten by carnivores.

Decomposer food chains begin with dead material—either animal wastes (feces) or the remains of plants and animals. These are consumed by insects, worms, and a host of microorganisms such as bacteria. These organisms are responsible for the decomposition of the waste and the return of its nutrients to the environment for reuse (recycling).

In ecosystems, decomposer and grazer food chains are tightly linked (FIGURE 4-8). Thus, waste from the grazer food chain enters the decomposer food chain. Nutrients liberated by the decomposer food chain enter the soil and water and are reincorporated into plants at the base of the grazer food chain.

Food chains exist only on the pages of textbooks; in a community of living organisms, food chains are part of a much more complex network of feeding interactions, **food webs** (FIGURE 4-9). Food webs present a complete picture of the feeding relationships in any given ecosystem.

As with so many other topics in ecology, an understanding of food chains and food webs is essential to living sustainably on the planet. For instance, efforts to protect the ozone layer, which shields the Earth from harmful ultraviolet radiation, are important to protect people from cancer, but they are also important because they protect phytoplankton in the world's oceans. Phytoplankton, small microscopic photosynthesizers, form the base of aquatic food chains. Ultraviolet radiation can kill phytoplankton and thus cause a collapse of aquatic food chains.

KEY CONCEPTS

Food and energy flow through food chains that are part of much larger food webs in ecosystems.

The Flow of Energy and Nutrients Through Food Webs

Energy and nutrients both flow through food webs, but in very different ways. Let us begin with energy. As you just learned, solar energy is first captured by plants and then used to produce organic food molecules. Energy from the sun is then stored in these molecules. In the food chain, organic molecules pass from plants to animals. In both plants and animals, the molecules are broken down. This process releases stored solar energy, which is used to power numerous cellular activities.

During cellular energy release, a good portion of the energy stored in organic food molecules is lost as heat. Heat escaping from plants and animals is radiated into the atmosphere and then into outer space. It cannot be recaptured and reused by plants or animals. Because all solar energy is eventually converted to heat, energy is said to flow unidirectionally through food chains and food webs. Put another way, energy cannot be recycled.

In contrast, nutrients flow cyclically; that is, they are recycled. Nutrients in the soil, air, and water are first in-

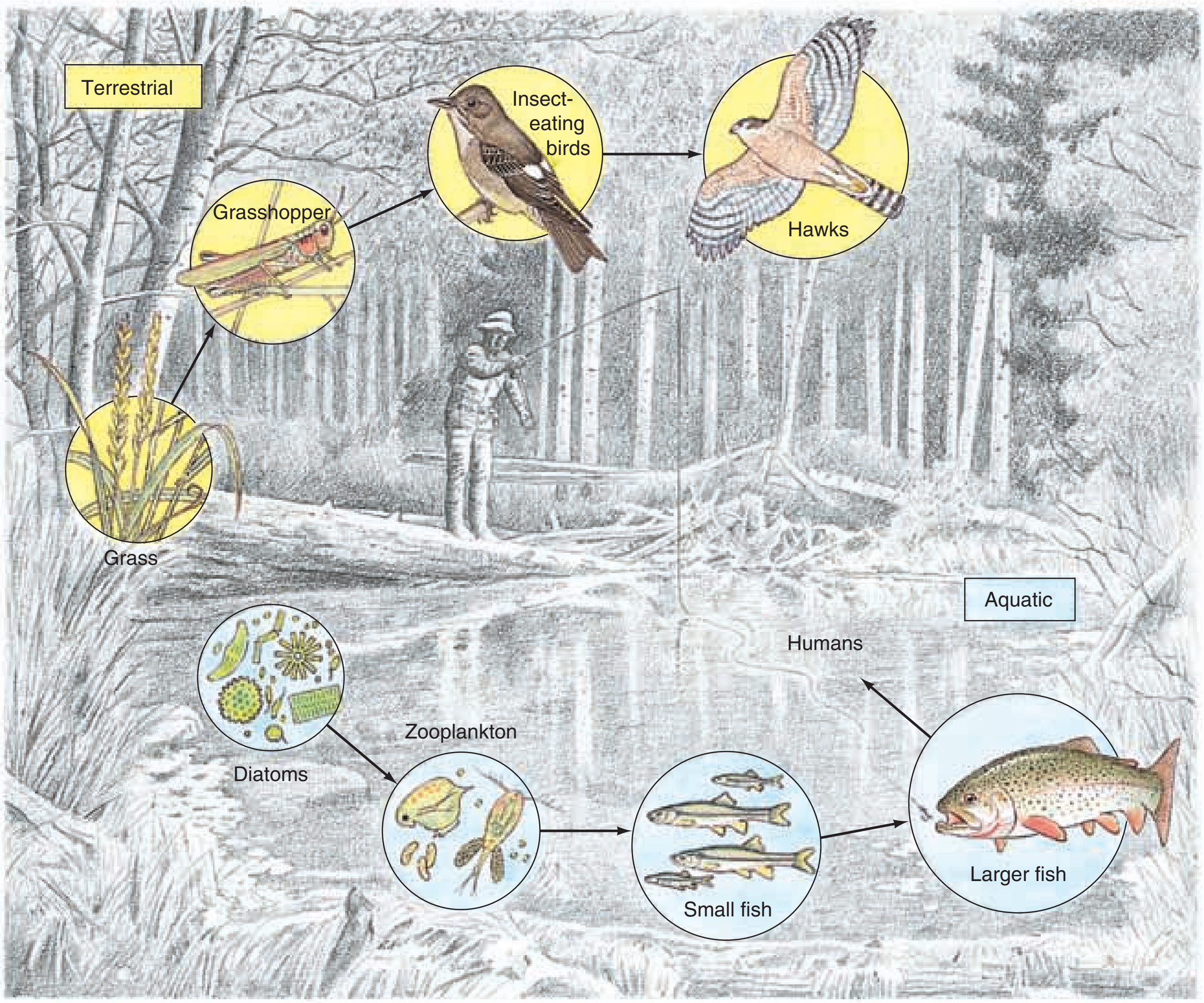


FIGURE 4-7 Simplified grazer food chains. These drawings show terrestrial (land-based) and aquatic grazer food chains.

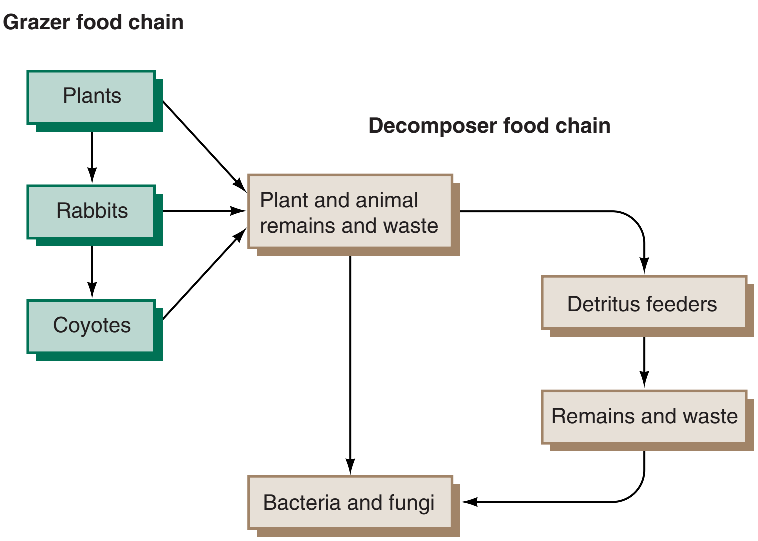


FIGURE 4-8 A grazer food chain and a decomposer food chain, showing the connection between the two.

corporated into plants and algae and are then passed from plants to animals in various food chains. Nutrients in the food chain eventually reenter the environment through waste or the decomposition of dead organisms.

Every time you exhale, for example, you release carbon dioxide, a waste product of cellular energy production. Carbon dioxide reenters the atmosphere for reuse. Thus, through the act of breathing you play an important role in the global recycling system that makes life possible. Other wastes must be decomposed before releasing their nutrients. The feces of a rhinoceros, for example, are broken down by bacteria, which liberate carbon dioxide, nitrogen, and minerals.

Nutrients also reenter the environment through the decomposition of dead organisms. When a plant or animal dies, bacteria and fungi devour its organic remains. This process is called **decomposition**.

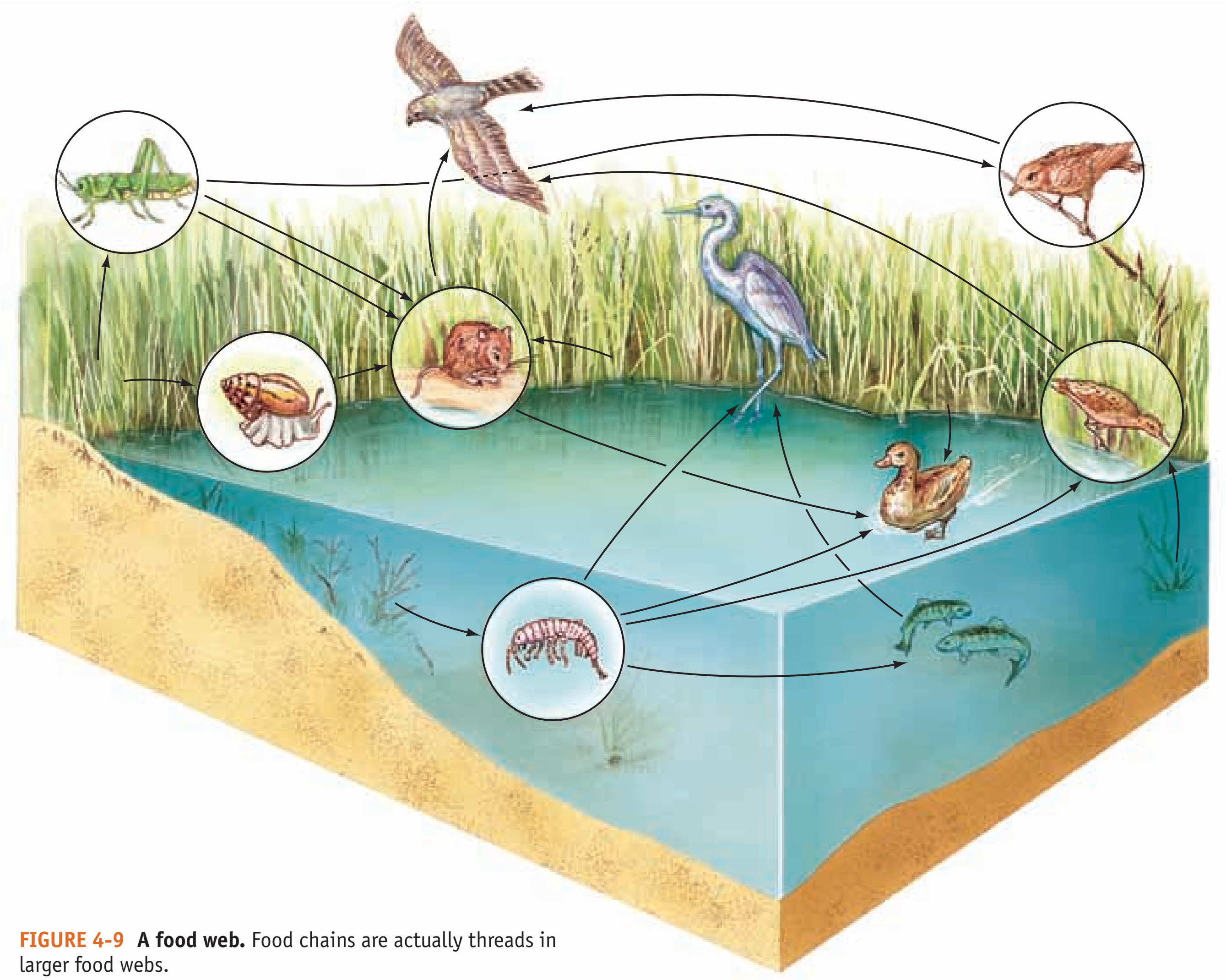


FIGURE 4-9 **A food web.** Food chains are actually threads in larger food webs.

Although these microorganisms absorb many nutrients released during this process, some nutrients escape and enter the soil and water for reuse. (Of course, when a bacterium dies, it also breaks down, releasing nutrients into its environment.)

One way or another, nutrients eventually make their way back to the environment for reuse. As a result, each new generation of organisms relies on the recycling of material in the biosphere. Every atom in your body has been recycled since the beginning of life on Earth. Perhaps some of those atoms were in the very first cells.

KEY CONCEPTS

Food chains are biological avenues for the flow of energy and the cycling of nutrients in the environment. Energy flows in one direction through food chains, but nutrients are recycled.

Trophic Levels

Ecologists classify the organisms in a food chain according to their position, or **trophic level** (literally, "feeding" level). The producers are the base of the grazer food chain and belong to the first trophic level. The grazers are part of the second trophic level. Carnivores that feed on grazers are in the third trophic level, and so on.

Most terrestrial food chains are limited to three or four trophic levels. Longer terrestrial food chains are rare because food chains generally do not have a large enough producer base to support many levels of consumers. Why not?

Plants absorb only a small portion of the sunlight that strikes the Earth (only 1 to 2%), which they use to produce organic matter, or biomass. Technically, **biomass** is the dry weight of living material in an ecosystem. The biomass at the first trophic level is the raw material for the second trophic level. The biomass at the second trophic level is the raw material for the third trophic level, and so on.

As shown at the top of **FIGURE 4-10**, not all of the biomass produced by plants is converted to grazer biomass. At least three reasons account for the incomplete transfer of biomass from one trophic level to the next. First, some of the plant material, such as the roots, is not eaten. Second, not all of the material that the grazers eat is digested. Third, some of the digested material is broken down to produce energy and heat and therefore cannot be used to build biomass in the grazers (Figure 4-10). As a rule, only 5 to 20% of the biomass at any trophic level is passed to the next

4-2 Colleges and Universities Go Green

All across North America, colleges and universities are taking steps to green their campuses. Campus green is not a new color. Many colleges and universities have been recycling waste and taking other measures to reduce their impact on the environment for many years.

Today's green movement is much deeper and greener, however, and is often designed to create a sustainable future. Over 300 colleges and universities in the United States, for instance, have joined the Campus Climate Challenge, aimed at reducing their contribution to global warming. They're buying renewable energy and implementing energy-efficiency measures that dramatically lower their carbon emissions.

Many colleges and universities are also building all new classrooms and other facilities to much higher, more energy-efficient standards using green building materials—often thanks to student insistence (**FIGURE 1**). The University of Vermont and the University of Denver, for instance, built green buildings to house their law schools. The Colorado College, where I teach, built new green science and art buildings. Dozens of others universities and colleges have followed suit.

FIGURE 1 The Tutt Science building at Colorado College, where the author is a visiting professor, is LEED-certified with many green features, including energy-efficient design, energy-efficient lighting, water-efficient bathrooms, and a host of environmentally friendly building materials.

The challenge of greening college campus can be enormous. In addition to dorms and classroom buildings, institutions of higher learning also maintain and operate office buildings, laundry service, food service, vehicle repair and maintenance, healthcare facilities, bookstores, restaurants, and even their own power plants. They're like a small city!

Leadership varies too. At most schools, students have taken the lead. They can often create change that would be nearly impossible for faculty and administration. At other schools, the administration and faculty have led the charge. Some colleges and universities have even appointed sustainability specialists who coordinate all sustainability activities on campus. Sustainability specialists are helpful to ensure continuity because the most avid supporters of such movements, the students, are on campus for a rather short period—either two or four years—and the task of greening a campus can take many years to accomplish.

Some governing bodies, which are in charge of entire university systems, like the University of California's Regents, have also taken a leadership role in campus greening. The UC Regents, for instance, established a Green Building Policy and Clean Energy Standard for all of the schools in the university system.

Financing green initiatives can be a challenge. With rising tuition costs, the administrations of many schools are reluctant to raise fees. Students, however, have actively pursued this avenue, pushing for small increases in fees to fund renewable energy and energy efficiency. Such campaigns are almost always overwhelmingly supported by the student body.

Students and faculty interested in learning more can find direction through the National Wildlife Federation's Campus Ecology Program. Another excellent resource is the Campus Sustainability Assessment Framework, which lists 170 social, environmental, political, and economic indicators to assess the sustainability of a college or university campus.

Although greening a campus can be a challenge, it does help colleges walk their talk. And it provides good hands-on experience for students who will someday work for corporations that are looking for ways to green their operations, too.

level. (The amount varies depending on the organisms involved in the food chain.)

When plotted on graph paper, the biomass at the various trophic levels forms a pyramid, the **biomass pyramid** (**FIGURE 4-11**). Because biomass contains energy (stored in the bonds between atoms), the biomass pyramid can be converted into a graph of the chemical energy in the various trophic levels. This graph is called an **energy pyramid**.

In most food chains, the number of organisms also decreases with each trophic level, forming a **pyramid of numbers**.

Knowledge of ecological pyramids helps us understand why people in many developing countries subsist on a diet of grains (corn, rice, or wheat) rather than meat. As shown in **FIGURE 4-12**, in the grain → human food chain on the right, 20,000 kilocalories of grain can feed 10 people for a day. (A kilocalorie is the same unit as a calorie.) If that amount of grain

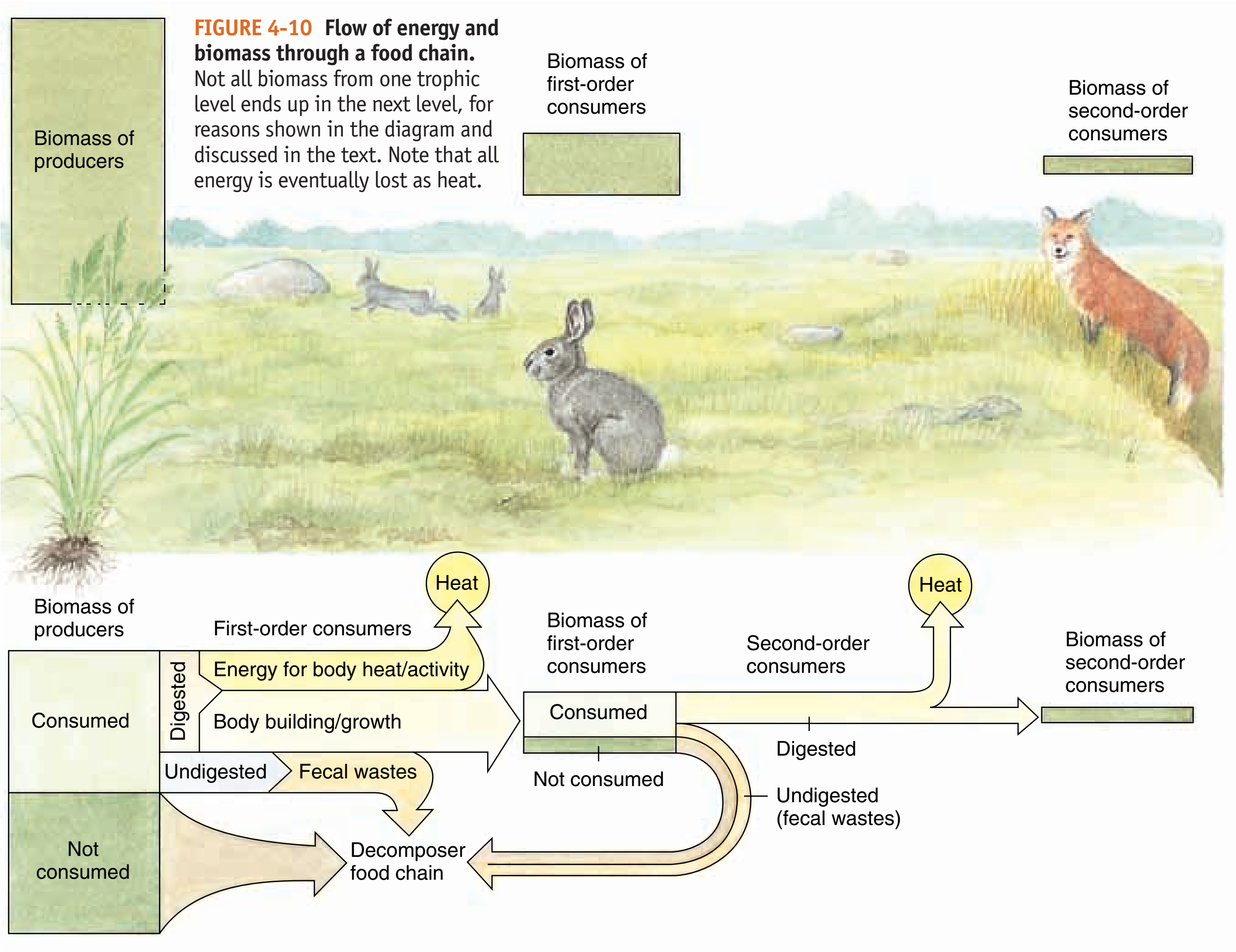


FIGURE 4-10 Flow of energy and biomass through a food chain. Not all biomass from one trophic level ends up in the next level, for reasons shown in the diagram and discussed in the text. Note that all energy is eventually lost as heat.

is fed to a steer and the beef is then fed to humans, however, only one person can subsist on the original 20,000 kilocalories. Why? In the grain → steer → human food chain, the 20,000 kilocalories fed to the cow that day produce only 2,000 kilocalories of food, barely enough to feed one person for a day (assuming a 10% transfer of biomass). Although people don't eat meat-only diets, this simplified example does illustrate a key point: the shorter the food chain, the more food is available to top-level consumers. (This is not a criticism of the cattle industry. Cattle often feed on grasses that grow on land too poor to support crops, although they are often fattened on grain for a year or so before being slaughtered.)

This simple rule has profound implications for the human race. The human population increases by about 73 to 74 million people a year. Feeding these people poses an enormous challenge. How can new residents be fed most efficiently?

The most efficient food source will be crops such as corn, rice, and wheat that are fed directly to people. It is far less efficient to feed corn and other grains to cattle and other livestock that are slaughtered for human consumption. Vegetarianism, say proponents, is not only good for your health but good for the environment because it requires less grain production than a nonvegetarian diet. It should be pointed out, however, that vegetarianism is not environmentally benign. Plowing former grasslands or forests to grow food for people has a profound impact on the environment. Fertilizer and pesticide use can have an enormous negative effect as well. Many wild animals are killed to grow grains.

Eating lower on the food chain is not always possible or advisable. In the case of grain-fed cattle, it may be both; but range-fed beef or elk are quite different. They feed on plants that are, of course, not edible for humans, and they live on land that would be poor farmland. Consuming meat from these sources may be a better option from an environmental perspective.

GO GREEN

Consider becoming a vegetarian or at least increasing your consumption of vegetables and reducing your intake of meat. A high vegetable diet is not only healthy, it can be better for the environment, as explained in the text.

KEY CONCEPTS

The position of an organism in a food chain is called its *trophic level*. Producers are on the first trophic level. Herbivores are on the second level. Carnivores are on the third level. The length of a food chain is limited by the loss of energy from one trophic level to another. The largest number of organisms is generally supported by the base of the food chain, the producers.

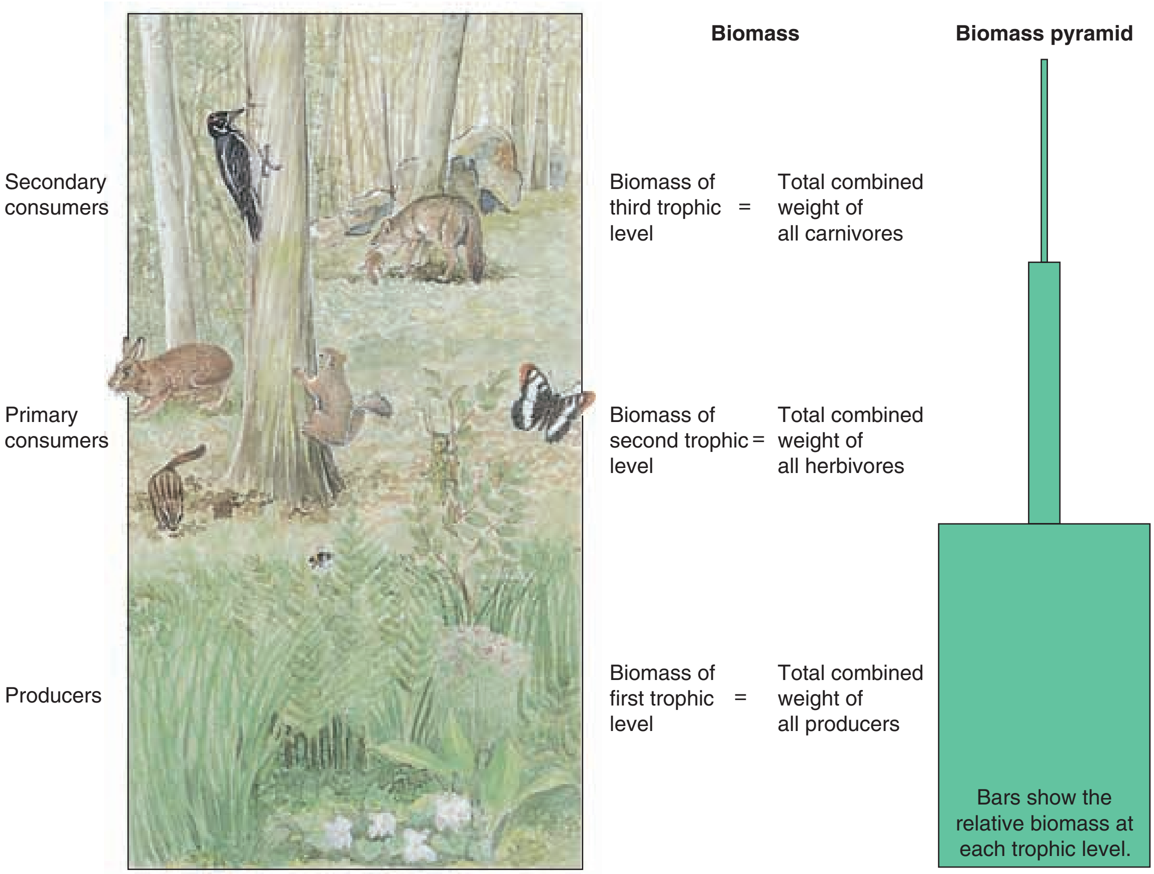


FIGURE 4-11 Biomass pyramid. In most food chains, biomass decreases from one trophic level to the next higher one.

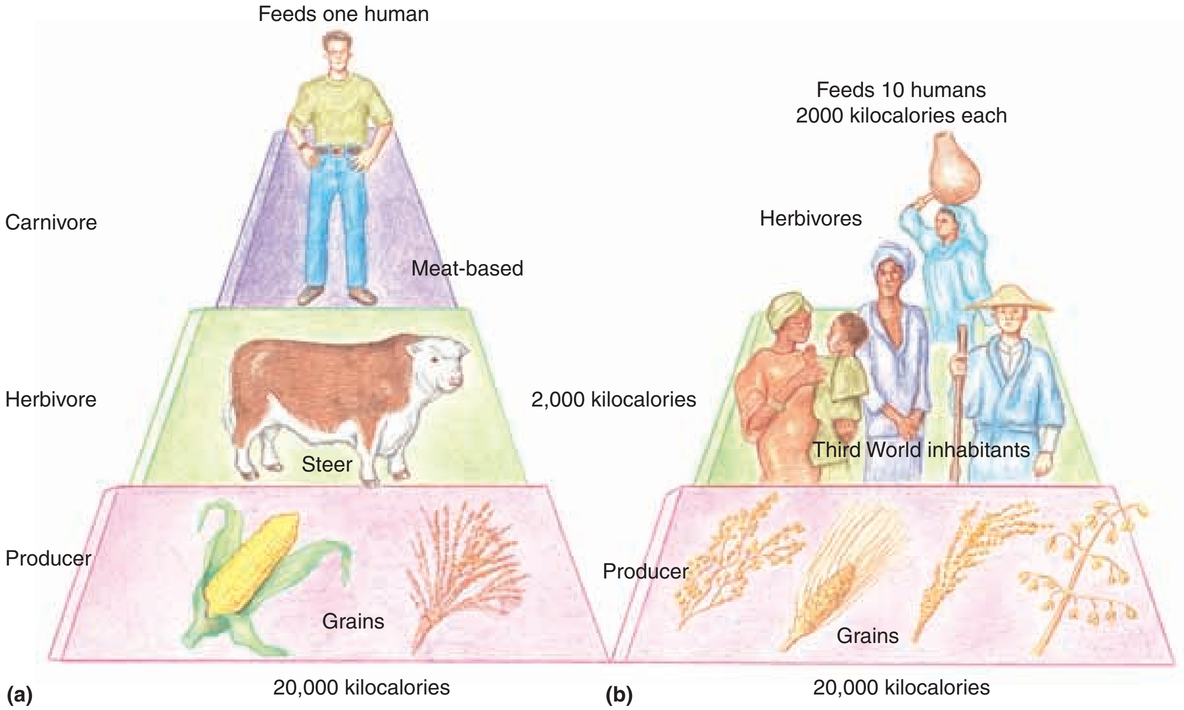


FIGURE 4-12 Energy pyramids in two food chains. (a) The typical meat-based diet. The 20,000 kilocalories of corn fed to cows produces only 2,000 kilocalories of meat. An adult needs only about 2,000 calories per day. **(b)** In a shorter food chain, 20,000 kilocalories can feed 10 people directly. This is the reason many people in developing nations subsist primarily on a vegetarian diet. Although few, if any, people eat a meat-only diet, this example does illustrate an important point: more food is available to those societies that eat lower on the food chain.

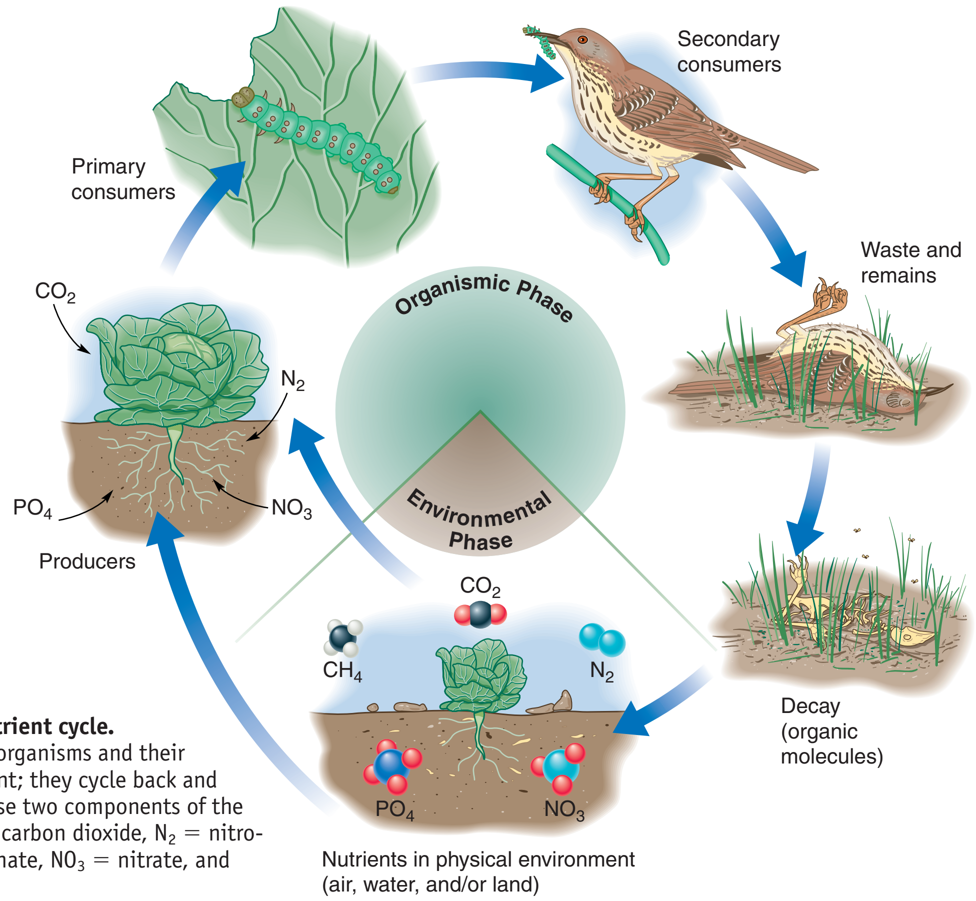


FIGURE 4-13 Nutrient cycle. Nutrients exist in organisms and their abiotic environment; they cycle back and forth between these two components of the ecosystem. CO_2 = carbon dioxide, N_2 = nitrogen, PO_4 = phosphate, NO_3 = nitrate, and CH_4 = methane.

Nutrient Cycles

The sustainability of natural systems results primarily from their dependence on the sun and their reliance on the recycling of nutrients, which ensures an adequate supply of life's essential ingredients. The term **nutrients** is used here to refer to all ions (charged atoms) and molecules used by living organisms.

In ecosystems, nutrients flow from the environment through food webs but are eventually released back into the environment. This circular flow constitutes a **nutrient cycle**, also known as a **biogeochemical cycle**.

Nutrient cycles can be divided broadly into environmental and organismic phases (FIGURE 4-13). In the **environmental phase**, a nutrient exists in the air, water, or soil, or sometimes in two or more of them simultaneously. In the **organismic phase**, nutrients are found in the biota—the plants, animals, and microorganisms.

Dozens of global nutrient cycles operate continuously to ensure the availability of chemicals vital to all living things, present and future. Unfortunately, however, a great many human activities disrupt nutrient cycles. These activities can profoundly influence the survival of species, including our own.

This section examines two of the most important nutrient cycles, the carbon and nitrogen cycles, and the ways they are being altered.

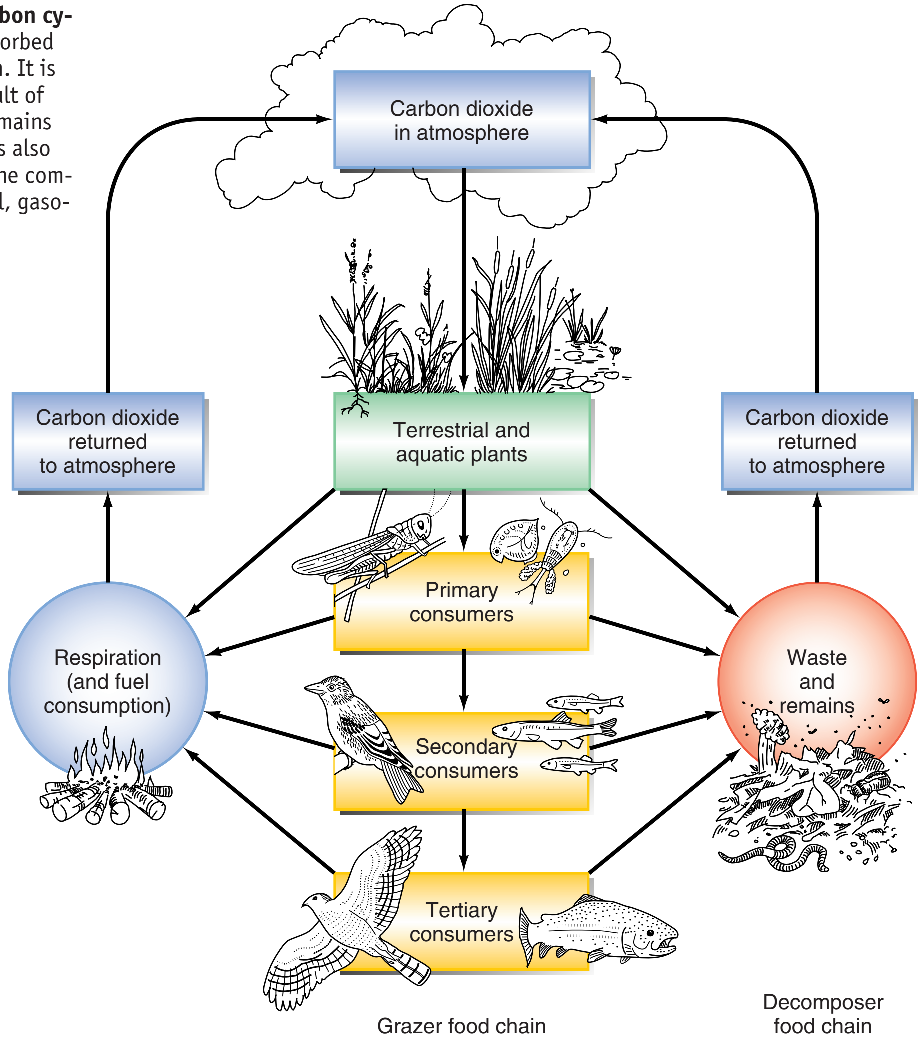
KEY CONCEPTS

Nutrients are recycled in global nutrient cycles. In these cycles, nutrients alternate between organisms and the environment. Humans can disrupt nutrient cycles in many ways, with profound impacts on ecosystems and our own future.

The Carbon Cycle The carbon cycle is shown in FIGURE 4-14 in a slightly simplified form. To understand how it operates, we begin with carbon dioxide. In the environmental phase of the cycle, carbon dioxide resides in two reservoirs, or sinks: the atmosphere and the surface water (oceans, lakes, and rivers). As illustrated, atmospheric carbon dioxide is absorbed by plants and other photosynthetic organisms in terrestrial ecosystems, thus entering the organismic phase of the cycle. These organisms convert carbon dioxide into organic food materials, which are passed along the food chain. Carbon dioxide reenters the environmental phase via cellular energy production (cellular respiration) of the organisms in the grazer and decomposer food chains.

For tens of thousands of years, our ancestors lived in relative harmony with nature. Because their numbers were small and their technology fairly primitive, they had little impact on the environment. With the advent of the Industrial Revolution, however, human beings began

FIGURE 4-14 A simplified view of the carbon cycle. Carbon dioxide in the atmosphere is absorbed by plants and passed through the food chain. It is released back into the environment as a result of the decomposition of the waste and dead remains of plants, animals, and other organisms. It is also released by cellular energy production and the combustion of organic materials such as coal, oil, gasoline, and wood.



to interfere with natural processes on a large scale. One of the victims has been the global carbon cycle. The widespread combustion of fossil fuels (which releases carbon dioxide) and rampant deforestation (which reduces carbon dioxide uptake) have overloaded the cycle with carbon dioxide.

For many years before the Industrial Revolution, global carbon dioxide production equaled carbon dioxide absorption by plants and algae. Today, 7 billion tons of carbon dioxide are added to the atmosphere each year. Three-quarters of the increase results from the combustion of fossil fuels such as the gasoline in our cars; the remaining quarter stems from deforestation, which reduces the amount of carbon dioxide absorbed by the planet's plants. Making matters worse, many forests are burned after cutting, further adding to the carbon dioxide levels in the atmosphere.

In the past 100 years, global atmospheric carbon dioxide levels have increased by around 30%. In the atmosphere, carbon dioxide traps heat escaping from Earth and reradiates it to the Earth's surface. As carbon dioxide levels increase, global temperatures rise. Such a rise could shift rainfall patterns, destroy agricultural production in many regions, and wipe out thousands of species. A rising global temperature might cause glaciers and the polar ice caps to melt, raising the sea level and flooding many low-lying coastal regions. Fortunately, there are many cost-effective strategies for reducing our dependence on fossil fuel. The most notable are energy efficiency and the use of renewable fuel—solar energy and wind, for example. Transitioning to these clean, reliable, and cost-effective fuels could help us ensure a healthy economy, continued prosperity, and a better future.

GO GREEN

In the summer, turn the thermostat setting up a little at night and when you are away from your home or apartment, for instance, from 78 to 82°F. In the winter, turn the heat down a little when you are sleeping or away, for instance, from 68 to 60–62°F. Doing so can make a substantial dent in your heating and cooling costs and reduce carbon dioxide emissions, helping to combat global warming.

KEY CONCEPTS

The carbon cycle is vital to the survival of the Earth's many species. It is the basis of food and energy production in the living world. It is also vital to maintaining global temperature. The carbon cycle is currently being flooded with excess carbon dioxide as a result of the combustion of fossil fuels and deforestation, which could have devastating effects on climate and ecosystems.

The Nitrogen Cycle Nitrogen is an element that is essential to many important biological molecules, including amino acids, DNA, and RNA. The Earth's atmosphere contains enormous amounts of it, but atmospheric nitrogen is in the form of nitrogen gas (N_2), which is unusable to all but a few organisms. As a result, atmospheric nitrogen must first be converted to a usable form, either nitrate or ammonia.

The conversion of nitrogen to ammonia is known as **nitrogen fixation**. It occurs in terrestrial and aquatic environments. As **FIGURE 4-15** shows, the roots of leguminous plants (peas, beans, clover, alfalfa, vetch, and others) contain small swellings called *root nodules*. Inside the nodules are bacteria that convert atmospheric nitrogen to ammonia (ammonium ions). Ammonia is also produced by bacteria called *cyanobacteria* that live in the soil. Once ammonia is produced, other soil bacteria convert it to nitrite and then to nitrate. Nitrates are incorporated by plants and used to make amino acids and nucleic acids. All consumers ultimately receive the nitrogen they require from plants.

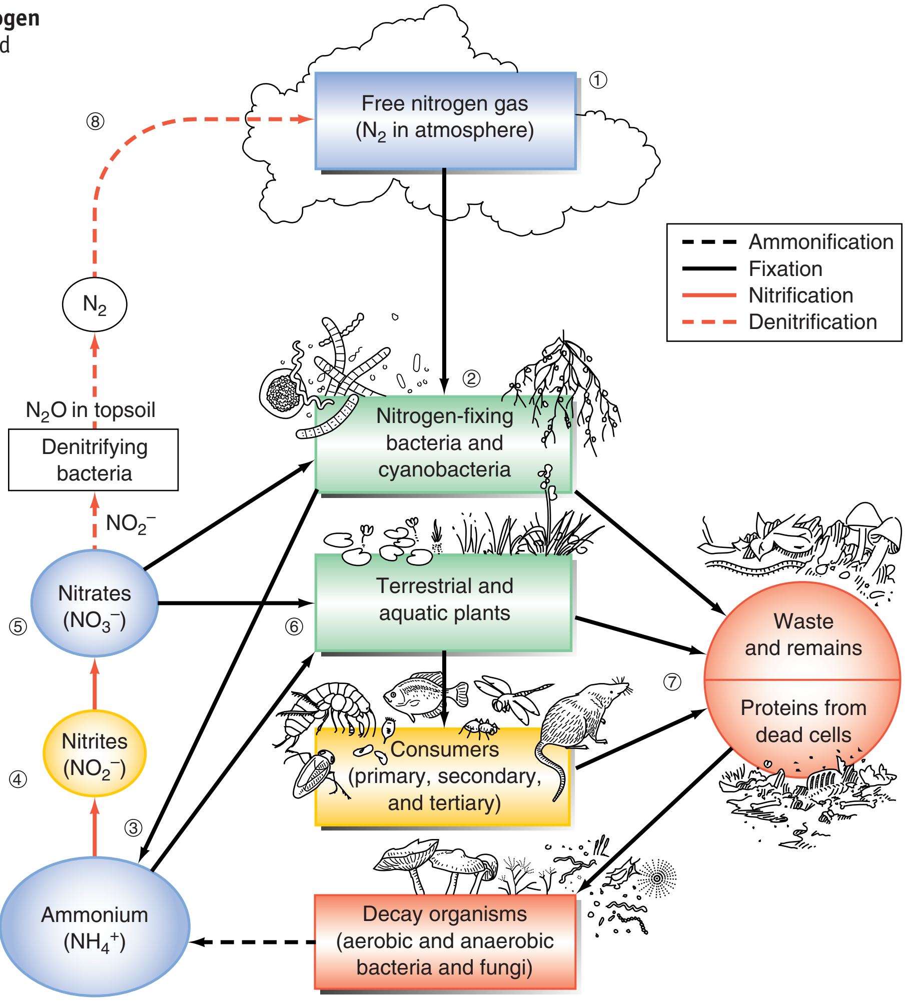
Nitrate in soil also comes indirectly from the decay of animal waste and the remains of plants and animals. As shown on the right side of Figure 4-15, decomposition returns ammonia to the soil for reuse. Ammonia is converted to nitrite, then to nitrate and reused. Some nitrate, however, may be converted to nitrite and then to nitrous oxide (N_2O) by denitrifying bacteria, as illustrated in Figure 4-15. Nitrous oxide is converted to nitrogen and released into the atmosphere.

Humans alter the nitrogen cycle in at least four ways: (1) by applying excess nitrogen-containing fertilizer on farmland, much of which ends up in waterways; (2) by disposing of nitrogen-rich municipal sewage in waterways; (3) by raising cattle in feedlots adjacent to waterways; and (4) by burning fossil fuels, which release a class of chemicals known as nitrogen oxides into the atmosphere. The first three activities increase the concentration of nitrogen in the

GO GREEN

Buy your parents a programmable thermostat and help them install it in their home. When used correctly it can cut heating and cooling costs by 10% per year.

FIGURE 4-15 A simplified view of the nitrogen cycle. Nitrogen in the atmosphere is converted into ammonium ions by bacteria in the soil. Ammonia is converted to nitrates and taken up by plants.



soil or water, upsetting the ecological balance. Nitrogen oxides released into the atmosphere by power plants, automobiles, and other sources are converted to nitric acid, which falls with rain or snow. Besides changing the pH (acidity) of soil and aquatic ecosystems, nitric acid also adds nitrogen to surface waters and may be responsible for 25% of the nitrogen pollution in some coastal waters in the United States.

Nitrogen, like phosphorus, is a plant nutrient. It stimulates the growth of aquatic plants and causes rivers and lakes to become congested with dense mats of vegetation, making them unnavigable. Sunlight penetration to deeper levels is also impaired by the growth of plants, causing oxygen levels in deeper waters to decline. In the autumn, when aquatic plants die and decay, oxygen levels may fall further, killing aquatic life.

Nothing can survive on the planet unless it is a cooperative part of a larger global life.

—Barry Commoner

CRITICAL THINKING

Exercise Analysis

It is difficult for me to know the list of misconceptions you came up with, but here are a few that might have arisen along the way. The exact meaning of the term *ecology* may have been one. Many people use it very loosely. You may not have understood the term *niche*, either. Like many people, you may have thought of it as a physical place an organism occupied, its *habitat*.

I suspect that your sense of the word *environment* has shifted. Now you can see that it includes biotic and abiotic components. The environment of an organism is quite complex.

I suspect that the discussion of the range of tolerance may have helped you to understand how our activities and natural events alter an organism's chances of survival.

What about energy? Has your understanding of energy changed? Do you see food chains and food webs now in a different light? Rather than being a simple matter of one organism feeding on another, food chains and food webs are elaborate pathways for the flow of nutrients and energy.

You may have gained new perspective on nutrient cycles. You may already have known that they existed, but did you know that humans are altering them in major ways?

CRITICAL THINKING AND CONCEPT REVIEW

1. "Humans are a part of nature." Do you agree or disagree with this statement? Support your answer.
2. Define the term *ecology* and give examples of its proper and improper use.
3. The Earth is a closed system. What does this mean, and what are the implications of this fact?
4. Define the following terms: *biosphere, biome, aquatic life zone*, and *ecosystem*.
5. Define the term *range of tolerance*. Using your knowledge of ecology, give some examples of ways in which humans alter the abiotic and biotic conditions of certain organisms. Describe the potential consequences of such actions.
6. Describe ways in which humans alter conditions within their own range of tolerance.
7. What is a limiting factor? Give some examples.
8. Define the following terms: *habitat, niche, producer, consumer, trophic level, food chain*, and *food web*.
9. A hunting advocate in your state is proposing the introduction of a foreign species, one very similar to deer, that he encountered in Russia on a hunting expedition. He thinks the introduced species will provide additional hunting opportunities and additional tax revenue for the state, which will be good for the economy. The governor is in favor of the proposal. Write a letter to the governor explaining what needs to be known about this species before it should be considered for introduction.
10. Explain why the biomass at one trophic level is less than the biomass at the next lower trophic level.
11. Outline the flow of carbon dioxide through the carbon cycle, and describe ways in which humans adversely influence the carbon cycle.
12. Using what you have learned about ecology, describe why it is important to protect natural ecosystems and other species.
13. With the knowledge you have gained, explain why it is beneficial to set aside habitat to protect an endangered species.
14. Looking back over the principles you have learned in this chapter, write a set of guidelines for human society that would help us live sustainably on the Earth.
15. Reread the Point/Counterpoint in this chapter. Which view do you agree with? Why? Is your support of one view based on values or science, or both?

KEY TERMS

abiotic
aquatic life zones
biogeochemical cycle
biological community
biomass
biomass pyramid
biome
biosphere
biotic
carnivores
closed system
competitive exclusion principle
consumers
decomposer food chains
decomposers
decomposition
desert biome
detritivores
ecological niche
ecological system
ecology
ecosystem
endangered species
energy pyramid
environmental phase
food chain
food webs
grassland biome
grazer food chains
habitat
herbivores
limiting factor
niche
nitrogen fixation
northern boreal forest
northern coniferous forest
nutrient cycle
nutrients
omnivores
optimum range
organismic phase
photosynthesis
population
producers
pyramid of numbers
range of tolerance
taiga
temperate deciduous forest biome
trophic level
tundra
zones of intolerance
zones of physiological stress
zones of tolerance

REFERENCES AND FURTHER READING

To save on paper and allow for updates, additional reading recommendations and the list of sources for the information discussed in this chapter are available at http://environment.jbpub.com/9e/.

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The site features eLearning, an online review area that provides quizzes, chapter outlines, and other tools to help you study for your class. You can also follow useful links for in-depth information, research the differing views in the Point/Counterpoints, or keep up on the latest environmental news.