Symbiotic Relationships

Symbiosis is a close, long-lasting, physical relationship between two different species. In other words, the two species are usually in physical contact and at least one of them derives some sort of benefit from this contact. There are three different categories of symbiotic relationships: parasitism, commensalism, and mutualism.

Parasitism

Parasitism is a relationship in which one organism, known as the **parasite,** lives in or on another organism, known as the **host,** from which it derives nourishment. Generally, the parasite is much smaller than the host. Although the host is harmed by the interaction, it is generally not killed immediately by the parasite, and some host individuals may live a long time and be relatively little affected by their parasites. Some parasites are much more destructive than others, however.

Newly established parasite-host relationships are likely to be more destructive than those that have a long evolutionary history. With a long-standing interaction between the parasite and the host, the two species generally evolve in such a way that they can accommodate one another. It is not in the parasite's best interest to kill its host. If it does, it must find another. Likewise, the host evolves defenses against the parasite, often reducing the harm done by the parasite to a level the host can tolerate.

Many parasites have complex life histories that involve two or more host species for different stages in the parasite's life cycle. Many worm parasites have their adult, reproductive stage in a carnivore (the definitive host), but they have an immature stage that reproduces asexually in another animal (the intermediate host) that the carnivore uses as food. Thus, a common dog tapeworm is found in its immature form in certain internal organs of rabbits.

Other parasite life cycles involve animals that carry the parasite from one host to another. These carriers are known as **vectors.** For example, many blood-feeding insects and mites can transmit parasites from one animal to another when they obtain blood meals from successive hosts. Malaria, Lyme disease, and sleeping sickness are transmitted by these kinds of vectors.

Parasites that live on the surface of their hosts are known as **ectoparasites.** Fleas, lice, mites, and some molds and mildews are examples of ectoparasites. Many other parasites, such as tapeworms, malaria parasites, many kinds of bacteria, and some fungi, are called **endoparasites** because they live inside the bodies of their hosts. A tapeworm lives in the intestines of its host, where it is able to resist being digested and makes use of the nutrients in the intestine. If a host has only one or two tapeworms, it can live for some time with little discomfort, supporting itself and its parasites. If the number of parasites is large, the host may die.

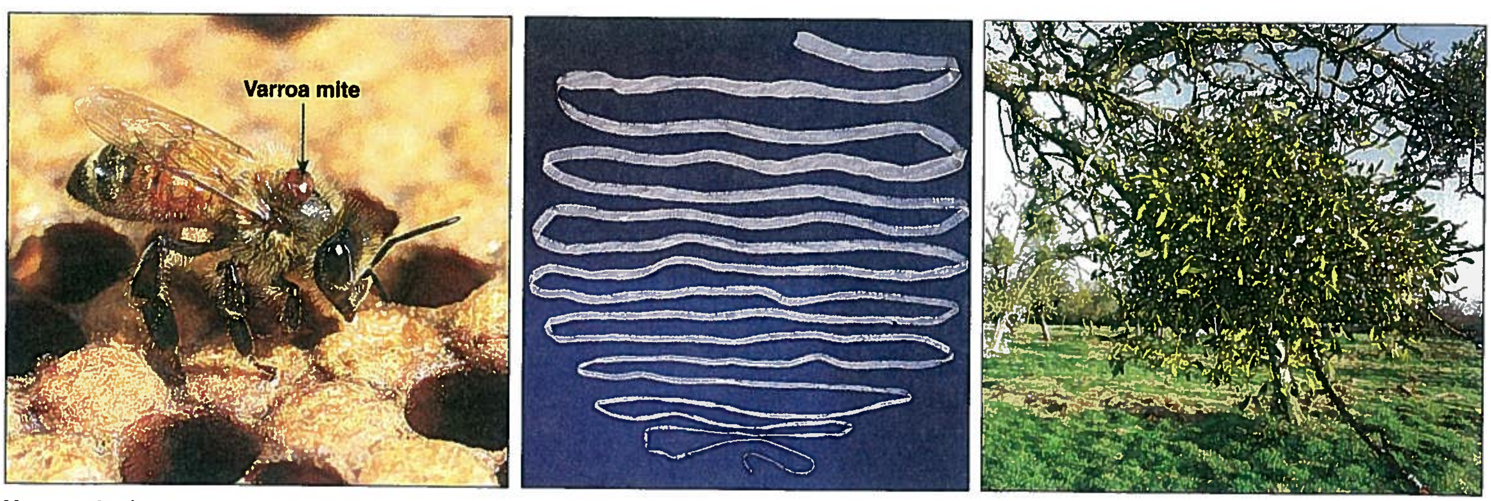
Even plants can be parasites. Mistletoe is a flowering plant that is parasitic on trees. It establishes itself on the surface of a tree when a bird transfers the seed to the tree. It then grows down into the water-conducting tissues of the tree and uses the water and minerals it obtains from these tissues to support its own growth.

Parasitism is a very common life strategy. If we were to categorize all the organisms in the world, we would find many more parasitic species than nonparasitic species. Each organism, including you, has many others that use it as a host. (See figure 5.20.)

Commensalism

Commensalism is a relationship between organisms in which one organism benefits while the other is not affected. It is possible to visualize a parasitic relationship evolving into a commensal one. Since parasites generally evolve to do as little harm to their host as possible and the host is combating the negative effects of the parasite, they might eventually evolve to the point where the host is not harmed at all.

Many examples of commensal relationships exist. Many orchids use trees as a surface upon which to grow. The tree is not harmed or helped, but the orchid needs a surface upon which to establish itself and also benefits by being close to the top of the tree,



Varroa mite (ectoparasite) **Tapeworm (endoparasite)** **Mistletoe**

FIGURE 5.20 **Parasitism** Varroa mites are ectoparasites on honeybees. They suck the body fluids of bees and severely weaken them. Tapeworms are endoparasites that live inside the intestines of their hosts, where they absorb food from their hosts' intestines. Mistletoe is a plant that is parasitic on other plants.

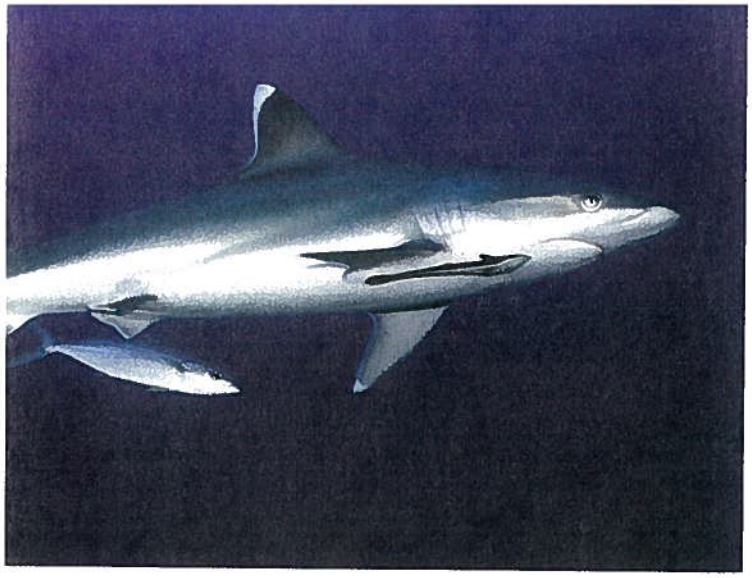


FIGURE 5.21 **Commensalism** Remoras hitch a ride on sharks and feed on the scraps of food lost by the sharks. This is a benefit to the remoras. The sharks do not appear to be affected by the presence of the remoras.

where it can get more sunlight and rain. Some mosses, ferns, and many vines also make use of the surfaces of trees in this way.

In the ocean, many sharks have a smaller fish known as a remora attached to them. Remoras have a sucker on the top of their heads that they can use to attach to the shark. In this way, they can hitch a ride as the shark swims along. When the shark feeds, the remora frees itself and obtains small bits of food that the shark misses. Then, the remora reattaches. The shark does not appear to be positively or negatively affected by remoras. (See figure 5.21.)

Many commensal relationships are rather opportunistic and may not involve long-term physical contact. For example, many birds rely on trees of many different species for places to build their nests but do not use the same tree year after year. Similarly, in the spring, bumblebees typically build nests in underground mouse nests that are no longer in use.

Mutualism

Mutualism is another kind of symbiotic relationship and is actually beneficial to both species involved. In many mutualistic relationships, the relationship is obligatory; the species cannot live without each other. In others, the species can exist separately but are more successful when they are involved in a mutualistic relationship. Some species of *Acacia,* a thorny tree, provide food in the form of sugar solutions in little structures on their stems. Certain species of ants feed on the solutions and live in the tree, which they will protect from other animals by attacking any animal that begins to feed on the tree. Both organisms benefit; the ants receive food and a place to live, and the tree is protected from animals that would use it as food.

One soil nutrient that is usually a limiting factor for plant growth is nitrogen. Many kinds of plants, such as legumes (beans, clover, and acacia trees) and alder trees, have bacteria that live in their roots in little nodules. The roots form these nodules when they are infected with certain kinds of bacteria. The bacteria do not cause disease but provide the plants with nitrogen-containing molecules that the plants can use for growth. The nitrogen-fixing bacteria benefit from the living site and nutrients that the plants provide, and the plants benefit from the nitrogen they receive. (See figure 5.22.)

(a)

(b)

FIGURE 5.22 **Mutualism** (a) The growths on the roots of this plant contain beneficial bacteria that make nitrogen available to the plant. The relationship is also beneficial to the bacteria, since the bacteria obtain necessary raw materials from the plant. It is a mutually beneficial relationship. (b) The oxpecker (bird) and the impala have a mutualistic relationship. The oxpecker obtains food by removing parasites from the surface of the impala and the impala benefits from a reduced parasite load.

Similarly, many kinds of fungi form an association with the roots of plants. The root-fungus associations are called **mycorrhizae.** The fungus obtains organic molecules from the roots of the plant, and the branched nature of the fungus assists the plant in obtaining nutrients such as phosphates and nitrates. In many cases, it is clear that the relationship is obligatory.

Some Relationships Are Difficult to Categorize

Sometimes it is not easy to categorize the relationships that organisms have with each other. For example, it is not always easy to say whether a relationship is a predator-prey relationship or a host-parasite relationship. How would you classify a mosquito or a tick? Both of these animals require blood meals to live and reproduce. They don't kill and eat their prey. Neither do they live in or on a host for a long period of time. This question points out the difficulty encountered when we try to place all kinds of organism interactions into a few categories. However, we can eliminate this problem if we call them temporary parasites or blood predators.

Another relationship that doesn't fit well is the relationship that certain birds such as cowbirds and European cuckoos have with other birds. Cowbirds and European cuckoos do not build nests but lay their eggs in the nests of other species of birds, who are left to care for a foster nestling at the expense of their own nestlings, who generally die. This situation is usually called nest parasitism or brood parasitism. (See figure 5.23.)

What about grazing animals? Are they predators or parasites on the plants that they eat? Sometimes they kill the plant they eat, while at other times they simply remove part of the plant and the rest continues to grow. In either case, the plant has been harmed by the interaction and the grazer has benefited.

There are also mutualistic relationships that do not require permanent contact between the participants in the relationship. Bees and the flowering plants they pollinate both benefit from their interactions. The bees obtain pollen and nectar for food and the plants are pollinated. But the active part of the relationship involves only a part of the life of any plant, and the bees are not restricted to any one species of plant for the food. They must actually switch to different flowers at different times of the year.

FIGURE 5.23 **Nest (Brood) Parasitism** This red-eyed vireo is feeding the nestling of a brown-headed cowbird. A female cowbird laid its egg in the vireo's nest. The vireo is harmed because it is not raising its own young, and the cowbird benefits because it did not need to expend energy to build and defend a nest or collect food for its own young.

COMMUNITY AND ECOSYSTEM INTERACTIONS

Thus far, we have discussed specific ways in which individual organisms interact with one another and with their physical surroundings. However, often it is useful to look at ecological relationships from a broader perspective. Two concepts that focus on relationships that involve many different kinds of interactions are community and ecosystem.

A **community** is an assemblage of all the interacting populations of different species of organisms in an area. Some species play minor roles, while others play major roles, but all are part of the community. For example, the grasses of the prairie have a major role, since they carry on photosynthesis and provide food and shelter for the animals that live in the area. Grasshoppers, prairie dogs, and bison are important consumers of grass. Meadowlarks consume many kinds of insects, and though they are a conspicuous and colorful part of the prairie scene, they have a relatively minor role and little to do with maintaining a prairie community. Bacteria and fungi in the soil break down the bodies of dead plants and animals and provide nutrients to plants. Communities consist of interacting populations of different species, but these species interact with their physical world as well.

An **ecosystem** is a defined space in which interactions take place between a community, with all its complex interrelationships, and the physical environment. The physical world has a major impact on what kinds of plants and animals can live in an area. We do not expect to see a banana tree in the Arctic or a walrus in the Mississippi River. Banana trees are adapted to warm, moist, tropical areas, and walruses require cold ocean waters. Some ecosystems, such as grasslands and certain kinds of forests, are shaped by periodic fires. The kind of soil and the amount of moisture also influence the kinds of organisms found in an area.

While it is easy to see that the physical environment places limitations on the kinds of organisms that can live in an area, it is also important to recognize that organisms impact their physical surroundings. Trees break the force of the wind, grazing animals form paths, and earthworms create holes that aerate the soil. While the concepts of community and ecosystem are closely related, an ecosystem is a broader concept because it involves physical as well as biological processes.

Every system has parts that are related to one another in specific ways. A bicycle has wheels, a frame, handlebars, brakes, pedals, and a seat. These parts must be organized in a certain way or the system known as a bicycle will not function. Similarly, ecosystems have parts that must be organized in specific ways or the systems will not operate. To more fully develop the concept of ecosystem, we will look at ecosystems from three points of view: the major roles played by organisms, the way energy is utilized within ecosystems, and the way atoms are cycled from one organism to another.

Major Roles of Organisms in Ecosystems

Ecologists have traditionally divided organisms' roles in ecosystems into three broad categories: producers, consumers, and decomposers.

Producers

Producers are organisms that are able to use sources of energy to make complex, organic molecules from the simple inorganic substances in their environment. In nearly all ecosystems, energy is supplied by the sun, and organisms such as plants, algae, and tiny aquatic organisms called phytoplankton use light energy to carry on photosynthesis. Since producers are the only organisms in an ecosystem that can trap energy and make new organic material from inorganic material, all other organisms rely on producers as a source of food, either directly or indirectly.

Consumers

Consumers are organisms that require organic matter as a source of food. They consume organic matter to provide themselves with energy and the organic molecules necessary to build their own bodies. An important part of their role is the process of respiration in which they break down organic matter to inorganic matter.

However, consumers can be further subdivided into categories based on the kinds of things they eat and the way they obtain food.

Primary consumers, also known as **herbivores,** are animals that eat producers (plants or phytoplankton) as a source of food. Herbivores, such as leaf-eating insects and seed-eating birds, are usually quite numerous in ecosystems, where they serve as food for the next organisms in the chain.

Secondary consumers or **carnivores** are animals that eat other animals. Secondary consumers can be further subdivided into categories based on what kind of prey they capture and eat. Some carnivores, such as ladybird beetles, primarily eat herbivores, such as aphids; others, such as eagles, primarily eat fish that are themselves carnivores. While these are interesting conceptual distinctions, most carnivores will eat any animal they can capture and kill.

In addition, many animals, called **omnivores,** include both plants and animals in their diet. Even animals that are considered to be carnivores (foxes, bears) regularly include large amounts of plant material in their diets. Conversely, animals often thought of as herbivores (mice, squirrels, seed-eating birds) regularly consume animals as a source of food. Parasites are also consumers that have a special way of obtaining their food.

Decomposers

Decomposers are organisms that use nonliving organic matter as a source of energy and raw materials to build their bodies. Whenever an organism sheds a part of itself, excretes waste products, or dies, it provides a source of food for decomposers. Since decomposers carry on respiration, they are extremely important in recycling matter by converting organic matter to inorganic material. Many small animals, fungi, and bacteria fill this niche. (See table 5.1.)

Keystone Species

Ecosystems typically consist of many different species interacting with each other and their physical surroundings. However, some species have more central roles than others. In recognition of this idea, ecologists have developed the concept of keystone species.

A **keystone species** is one that has a critical role to play in the maintenance of specific ecosystems. In prairie ecosystems, grazing animals are extremely important in maintaining the mix of species typical of a grassland. Without the many influences of the grazers, the nature of the prairie changes. A study of the American tallgrass prairie indicated that when bison are present, they increase the biodiversity of the site. Bison typically eat grasses and, therefore, allow smaller plant species that would normally be shaded by tall grasses to be successful. In ungrazed plots, the tall grasses become the dominant vegetation and biodiversity decreases. Bison also dig depressions in the soil, called wallows, to provide themselves with dust or mud with which they can coat themselves. These wallows retain many species of plants that typically live in disturbed areas. Bison urine has also been shown to be an important source of nitrogen for the plants.

The activities of bison even affect the extent and impact of fire, another important feature of grassland ecosystems. Since bison prefer to feed on recently burned sites and revisit these sites several times throughout the year, they tend to create a patchwork

TABLE 5.1 Roles in an Ecosystem

Category	Major Role or Action	Examples
Producer	Converts simple inorganic molecules into organic molecules by the process of photosynthesis	Trees, flowers, grasses, ferns, mosses, algae
Consumer	Uses organic matter as a source of food	Animals, fungi, bacteria
Herbivore	Eats plants directly	Grasshopper, elk, human vegetarian
Carnivore	Kills and eats animals	Wolf, pike, dragonfly
Omnivore	Eats both plants and animals	Rats, raccoons, most humans
Scavenger	Eats meat but often gets it from animals that died by accident or illness, or were killed by other animals	Coyote, vulture, blowflies
Parasite	Lives in or on another living organism and gets food from it	Tapeworm, many bacteria, some insects
Decomposer	Returns organic material to inorganic material; completes recycling of atoms	Fungi, bacteria, some insects and worms

have a continuous input of energy to retain its stability. The only significant source of energy for most ecosystems is sunlight. Producers are the only organisms that are capable of trapping solar energy through the process of photosynthesis and making it available to the ecosystem. The energy is stored in the form of chemical bonds in large organic molecules such as carbohydrates (sugars, starches), fats, and proteins. The energy stored in the molecules of producers is transferred to other organisms when the producers are eaten.

FIGURE 5.24 **A Keystone Species** Bison are a keystone species in prairie ecosystems. They affect the kinds of plants that live in an area, provide nutrients in the form of urine and manure, and produce wallows that provide special habitats for certain plants and animals.

of grazed and ungrazed areas. The grazed areas are less likely to be able to sustain a fire, and fires likely will be more prevalent in ungrazed patches. (See figure 5.24.)

The concept of keystone species has also been studied in marine ecosystems. The relationship among sea urchins, sea otters, and kelp forests suggests that sea otters are a keystone species. Sea otters eat sea urchins, which eat kelp. A reduction in the number of otters results in an increase in the number of sea urchins. Increased numbers of sea urchins lead to heavy grazing of the kelp by sea urchins. When the amount of kelp is severely reduced, fish and many other animals that live within the kelp beds lose their habitat and biodiversity is significantly reduced.

The concept of keystone species is useful to ecologists and resource managers because it helps them to realize that all species cannot be treated equally. Some species have pivotal roles, and their elimination or severe reduction can significantly alter ecosystems. In some cases, the loss of a keystone species can result in the permanent modification of an ecosystem into something considerably different from the original mix of species.

Energy Flow Through Ecosystems

An ecosystem is a stable, self-regulating unit. This does not mean that an ecosystem is unchanging. The organisms within it are growing, reproducing, dying, and decaying. In addition, an ecosystem must

Trophic Levels

Each step in the flow of energy through an ecosystem is known as a **trophic level.** Producers (plants, algae, phytoplankton) constitute the first trophic level, and herbivores constitute the second trophic level. Carnivores that eat herbivores are the third trophic level, and carnivores that eat other carnivores are the fourth trophic level. Omnivores, parasites, and scavengers occupy different trophic levels, depending on what they happen to be eating at the time. If we eat a piece of steak, we are at the third trophic level; if we eat celery, we are at the second trophic level. (See figure 5.25.)

Energy Relationships

The second law of thermodynamics states that whenever energy is converted from one form to another, some of the energy is converted to a nonuseful form (typically, low-quality heat). Thus, there is always less useful energy following an energy conversion. When energy passes from one trophic level to the next, there is less useful energy left with each successive trophic level. This loss

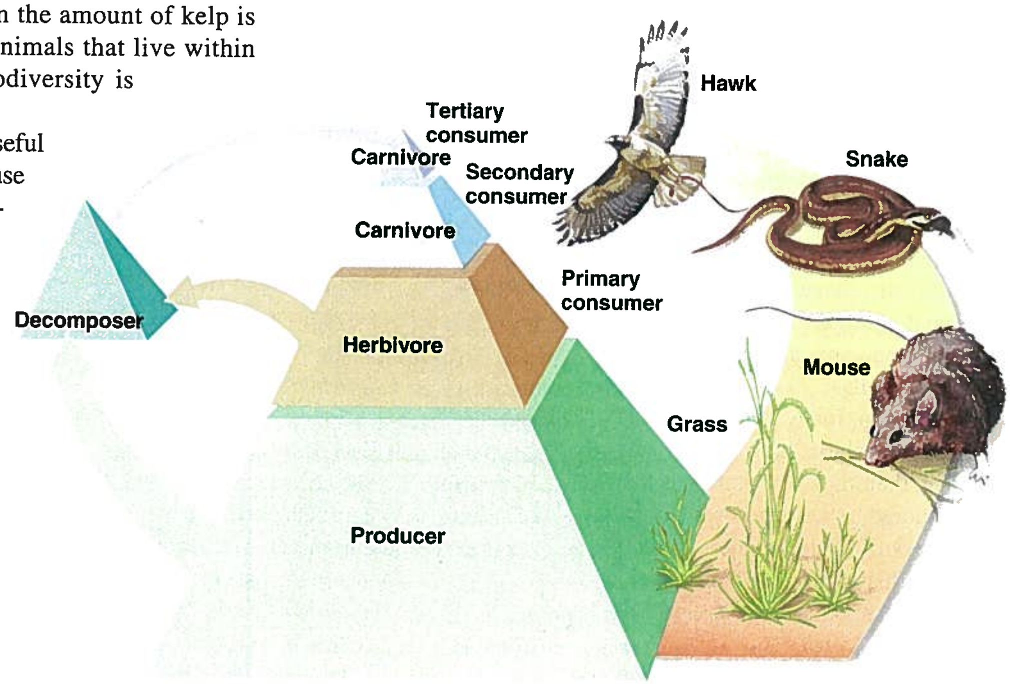


FIGURE 5.25 **Categories of Organisms Within an Ecosystem** Organisms within ecosystems can be placed in several broad categories based on how they obtain the energy they need for their survival.

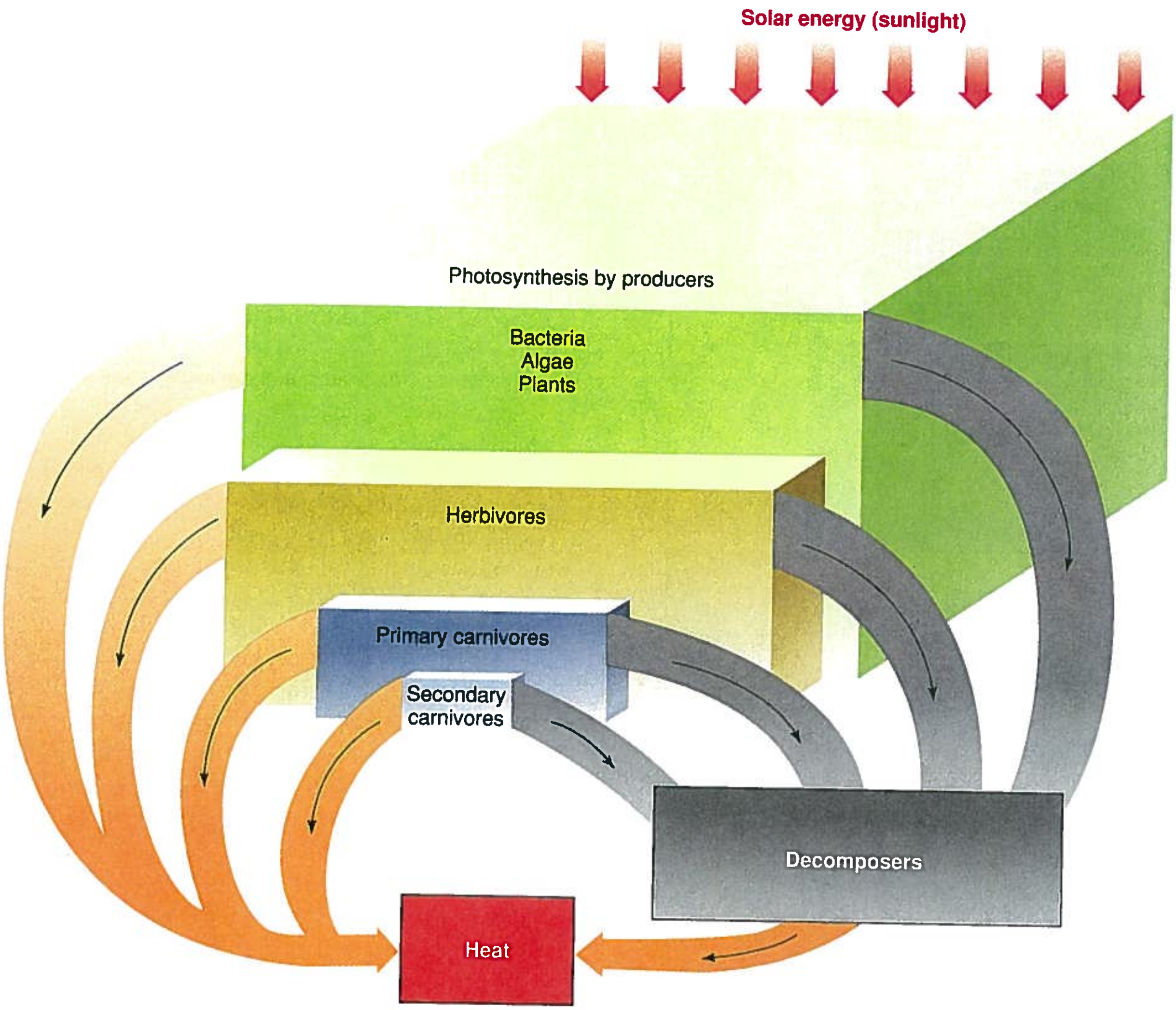


FIGURE 5.26 **Energy Flow Through Ecosystems** As energy flows through an ecosystem, it passes through several levels known as trophic levels. Each trophic level contains a certain amount of energy. Each time energy flows to another trophic level, approximately 90 percent of the useful energy is lost, usually as heat to the surroundings. Therefore, in most ecosystems, higher trophic levels contain less energy and fewer organisms.

of low-quality heat is dissipated to the surroundings and warms the air, water, or soil. In addition to this loss of heat, organisms must expend energy to maintain their own life processes. It takes energy to chew food, defend nests, walk to waterholes, or produce and raise offspring. Therefore, the amount of energy contained in higher trophic levels is considerably less than that at lower levels. Approximately 90 percent of the useful energy is lost with each transfer to the next highest trophic level. So in any ecosystem, the amount of energy contained in the herbivore trophic level is only about 10 percent of the energy contained in the producer trophic level. The amount of energy at the third trophic level is approximately 1 percent of that found in the first trophic level. (See figure 5.26.)

Because it is difficult to actually measure the amount of energy contained in each trophic level, ecologists often use other measures to approximate the relationship between the amounts of energy at each level. One of these is the biomass. The **biomass** is the weight of living material in a trophic level. It is often possible in a simple ecosystem to collect and weigh all the producers, herbivores, and carnivores. The weights often show the same 90 percent loss from one trophic level to the next as happens with the amount of energy.

Food Chains and Food Webs

A **food chain** is a series of organisms occupying different trophic levels through which energy passes as a result of one organism consuming another. For example, willow trees grow well in very moist soil, perhaps near a pond. The trees' leaves capture sunlight and convert carbon dioxide and water into sugars and other organic molecules. The leaves serve as a food source for insects, such as caterpillars, grasshoppers, and leaf beetles, that have chewing mouthparts and a digestive system adapted to plant food. Some of these insects are eaten by spiders, which fall from the trees into the pond below, where they are consumed by a frog. As the frog swims from one lily pad to another, a large bass consumes the frog. A human may use an artificial frog as a lure to entice the bass from its hiding place. A fish dinner is the final step in this chain of events that began with the leaves of a willow tree. (See figure 5.27.) This food chain has six trophic

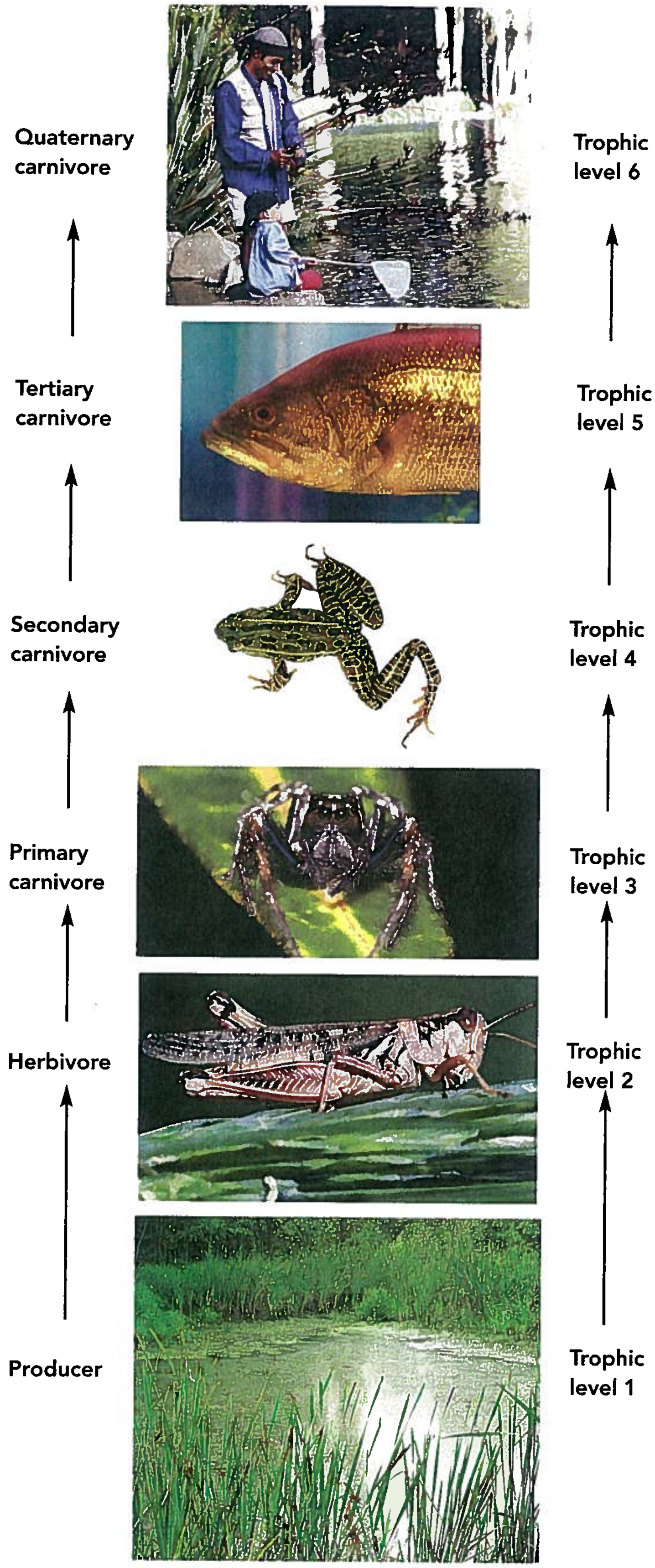


FIGURE 5.27 Trophic Levels in a Food Chain As one organism feeds on another organism, energy flows through the series. This is called a food chain.

levels. Each organism occupies a specific niche and has special abilities that fit it for its niche, and each organism in the food chain is involved in converting energy and matter from one form to another.

Some food chains rely on a constant supply of small pieces of dead organic material coming from situations where photosynthesis is taking place. The small bits of nonliving organic material are called **detritus.** Detritus food chains are found in a variety of situations. The bottoms of the deep lakes and oceans are too dark for photosynthesis. The animals and decomposers that live there rely on a steady rain of small bits of organic matter from the upper layers of the water where photosynthesis does take place. Similarly, in most streams, leaves and other organic debris serve as the major source of organic material and energy.

In another example, the soil on a forest floor receives leaves, which fuel a detritus food chain. A mixture of insects, crustaceans, worms, bacteria, and fungi cooperates in the breakdown of the large pieces of organic matter, while at the same time feeding on one another. When a leaf dies and falls to the forest floor, it is colonized by bacteria and fungi, which begin the breakdown process. An earthworm will also feed on the leaf and at the same time consume the bacteria and fungi. If that earthworm is eaten by a bird, it becomes part of a larger food chain that includes material from both a detritus food chain and a photosynthesis-driven food chain. When several food chains overlap and intersect, they make up a **food web.** (See figure 5.28.) This diagram is typical of the kinds of interactions that take place in a community. Each organism is likely to be a food source for several other kinds of organisms. Even the simplest food webs are complex.

Nutrient Cycles in Ecosystems—Biogeochemical Cycles

All matter is made up of atoms. These atoms are cycled between the living and nonliving portions of an ecosystem. The activities involved in the cycling of atoms include biological, geological, and chemical processes. Therefore, these nutrient cycles are often called **biogeochemical cycles.**

Some atoms are more common in living things than are others. Carbon, nitrogen, oxygen, hydrogen, and phosphorus are found in important organic molecules such as proteins, DNA, carbohydrates, and fats, which are found in all kinds of living things. Organic molecules contain large numbers of carbon atoms attached to one another. These organic molecules are initially manufactured from inorganic molecules by the activities of producers and are transferred from one living organism to another in food chains. The processes of respiration and decay ultimately break down the complex organic molecules of organisms and convert them to simpler, inorganic constituents that are returned to the abiotic environment. In this section, we will look at the flow of three kinds of atoms within communities and between the biotic and abiotic portions of an ecosystem: carbon, nitrogen, and phosphorus.

Carbon Cycle

All living things are composed of organic molecules that contain atoms of the element carbon. The **carbon cycle** includes the processes and pathways involved in capturing inorganic

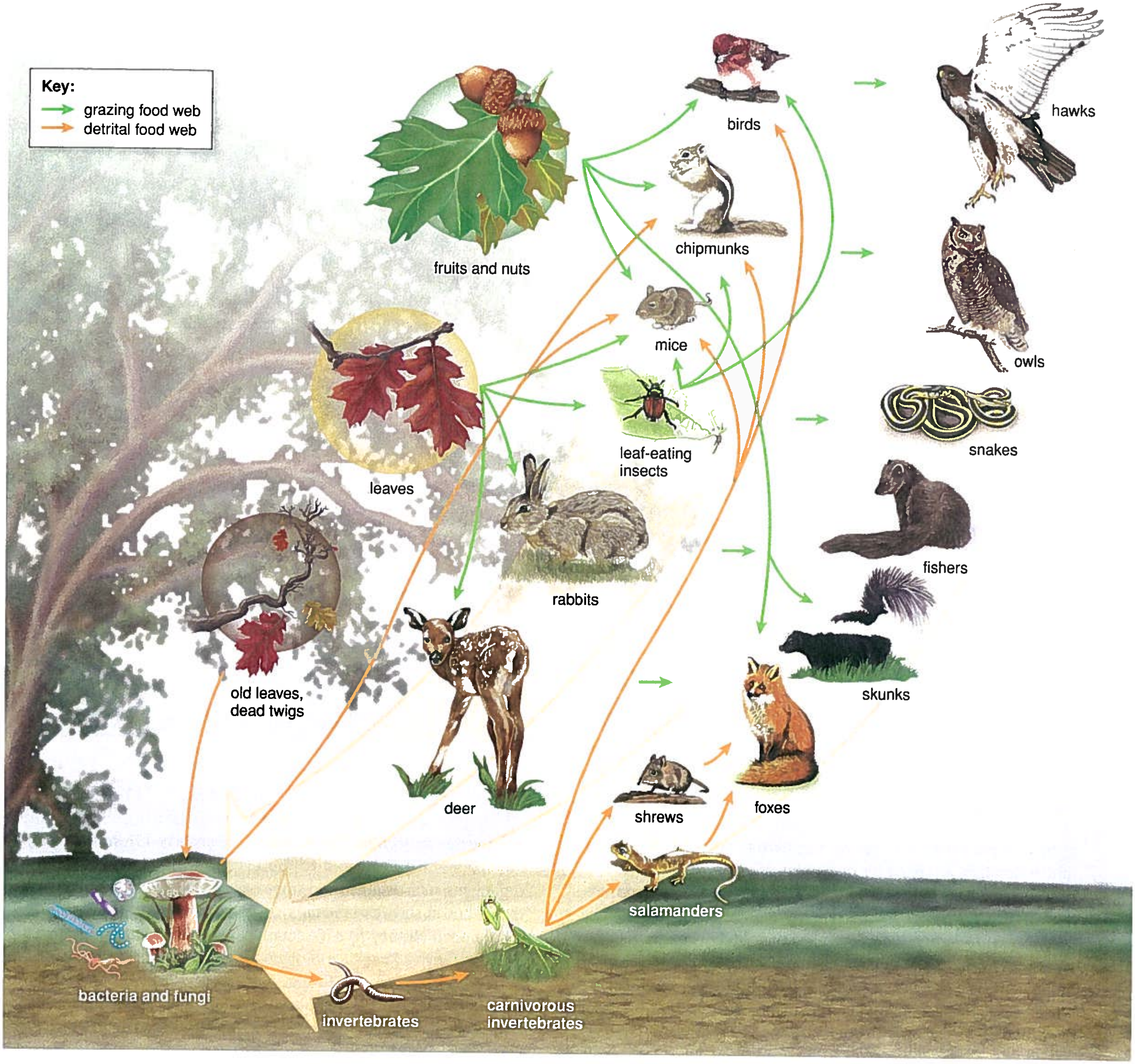


FIGURE 5.28 **Food Web** As organisms feed on one another, they establish a web of relationships known as a food web. This illustration shows the interactions between grazing and detrital food webs. Grazing food webs begin with photosynthesis by plants and the animals that eat plants. Since all organisms die, they ultimately become part of a detrital food web.

Water Connections

CHANGES IN THE FOOD CHAIN OF THE GREAT LAKES

Many kinds of human activity aid the distribution of species from one location to another. The construction of canals and locks in the Great Lakes basin has allowed ocean-going ships to enter the Great Lakes. These vessels often pump water into their holds to provide ballast when they do not have a full load of cargo. That water is pumped out when cargo is added. Since these vessels may add ballast water in Europe and empty it in the Great Lakes, it is highly likely that organisms will be transported from one location to another. Many species have made this trip and some of them appear to have caused profound changes in the food chain of the Great Lakes.

The introduction of the zebra and quagga mussels is correlated with several changes in the food web of the Great Lakes. Both mussels reproduce rapidly and attach themselves to any hard surface, including other mussels. They are very efficient filter-feeders that remove organic matter and small organisms from the water. Measurements of the abundance of diatoms and other tiny algae show that they have declined greatly—up to 90 percent in some areas where zebra or quagga mussels are common. There has been a corresponding increase in the clarity of the water. In many areas, a person can see twice as far into the water as previously.

Diporeia

Zebra mussels

Diporeia is a bottom-feeding crustacean that feeds on organic matter that falls to the lake bottom. Populations of *Diporeia* have declined by 70 percent in many places in the Great Lakes. Many feel that this decline is the result of a reduction in their food sources, which are being removed from the water by zebra and quagga mussels. Since *Diporeia* is major food organism for many kinds of bottom-feeding fish, there has been a ripple effect through the food chain. Recently, whitefish that rely on *Diporeia* as a food source have shown a decline in body condition. Other bottom-feeding fish that eat *Diporeia* serve as a food source for larger predator fish. There have been recent declines in the populations and physical condition of some of these predator fish.

Another phenomenon that is correlated with the increase in mussels is an increased frequency of toxic algal blooms in the Great Lakes. Although there are no clear answers to why this is occurring, two suggested links have been tied to zebra mussels. The clarity of the water may be encouraging the growth of the toxic algae or the mussels may be selectively rejecting toxic algae as food, while consuming the nontoxic algae. Thus, the toxic algae have a competitive advantage.

Finally, wherever zebra or quagga mussels are common, species of native mussels and clams have declined. There may be several reasons for this correlation. First, the zebra and quagga mussels are in direct competition with the native species and since they are very efficient at removing food from the water, these exotic species may be outcompeting the native species for food. Second, since zebra and quagga mussels attach to any hard surface, they attach to native clams, essentially burying them.

carbon-containing molecules, converting them into organic molecules that are used by organisms, and the ultimate release of inorganic carbon molecules back to the abiotic environment. (See figure 5.29.)

The same carbon atoms are used over and over again. In fact, you are not exactly the same person today that you were yesterday. Some of your carbon atoms are different. Furthermore, those carbon atoms have been involved in many other kinds of living things over the past several billion years. Some of them were temporary residents in dinosaurs, extinct trees, or insects, but at this instant, they are part of you.

1. The Role of Producers Carbon and oxygen combine to form the molecule carbon dioxide (CO_2), which is present in small quantities as a gas in the atmosphere and dissolved in water. During photosynthesis, carbon dioxide from the atmosphere is taken into the leaves of plants where it is combined with hydrogen from water molecules (H_2O), which are absorbed from the soil by the roots and transported to the leaves. Many kinds of aquatic organisms such as algae and some bacteria also perform photosynthesis but absorb carbon dioxide and water molecules from the water in which they live. (Actually about 50 percent of photosynthetic activity takes place in the oceans.)

The energy needed to perform photosynthesis is provided by sunlight. As a result of photosynthesis, complex organic molecules such as carbohydrates (sugars) are formed. Oxygen molecules (O_2) are released into the atmosphere or water during the process of photosynthesis because water molecules are split to provide hydrogen atoms necessary to manufacture carbohydrate molecules. The remaining oxygen is released as a waste product of photosynthesis. In this process, light energy is converted to chemical-bond energy in organic molecules, such as sugar. Plants and other producer organisms use these sugars for growth and to provide energy for other necessary processes.

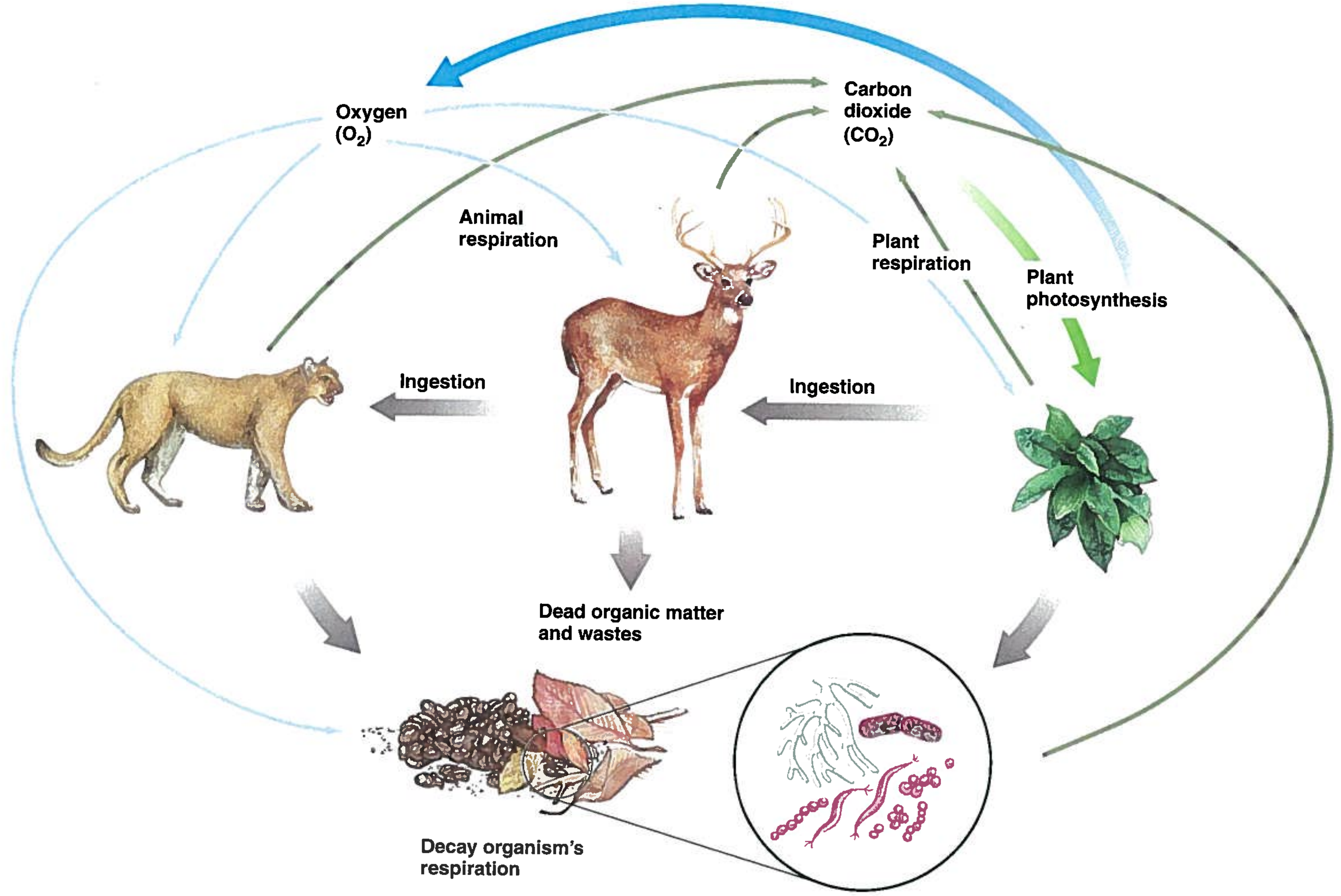


FIGURE 5.29 **Carbon Cycle** Carbon atoms are cycled through ecosystems. Plants can incorporate carbon atoms from carbon dioxide into organic molecules when they carry on photosynthesis. The carbon-containing organic molecules are passed to animals when they eat plants or other animals. Organic wastes or dead organisms are consumed by decay organisms. All organisms, plants, animals, and decomposers return carbon atoms to the atmosphere when they carry on respiration. Oxygen atoms are being cycled at the same time that carbon atoms are being cycled.

2. The Role of Consumers Herbivores can use these complex organic molecules as food. When an herbivore eats plants or algae, it breaks down the complex organic molecules into simpler organic molecular building blocks, which can be reassembled into the specific organic molecules that are part of the herbivore's chemical structure. The carbon atom, which was once part of an organic molecule in a producer, is now part of an organic molecule in an herbivore. Nearly all organisms also carry on the process of respiration, in which oxygen from the atmosphere is used to break down large organic molecules into carbon dioxide and water. Much of the chemical-bond energy is released by respiration and is lost as heat, but the remainder is used by the herbivore for movement, growth, and other activities.

In similar fashion, when an herbivore is eaten by a carnivore, some of the carbon-containing molecules of the herbivore become incorporated into the body of the carnivore. The remaining organic molecules are broken down in the process of respiration to obtain energy, and carbon dioxide and water are released.

3. The Role of Decomposers The organic molecules contained in animal waste products and dead organisms are acted upon by decomposers that use these organic materials as a source of food. The decay process of decomposers involves respiration and releases carbon dioxide and water so that naturally occurring organic molecules are typically recycled.

4. The Role of Fossil Fuels Fossil fuels (coal, oil, and natural gas) are part of the carbon cycle as well. At one time, these materials were organic molecules in the bodies of living organisms. The organisms were buried and the organic compounds in their bodies were modified by geologic forces. Thus, the carbon atoms present in fossil fuels were removed temporarily from the active, short-term carbon cycle. When we burn fossil fuels, the carbon reenters the active carbon cycle.

Nitrogen Cycle

The **nitrogen cycle** involves the cycling of nitrogen atoms between the abiotic and biotic components and among the organisms in an ecosystem. Seventy-eight percent of the gas in the air we breathe is made up of molecules of nitrogen gas (N_2). However, the two nitrogen atoms are bound very tightly to each other, and very few organisms are able to use nitrogen in this form. Since plants and other producers are at the base of nearly all food chains, they must make new nitrogen-containing molecules, such as proteins and DNA. Plants and other producers are unable to use the nitrogen in the atmosphere and must get it in the form of nitrate (NO_3^-) or ammonia (NH_3).

1. The Role of Nitrogen-Fixing Bacteria Because atmospheric nitrogen is not usable by plants, nitrogen-containing compounds are often in short supply and the availability of nitrogen is often a factor that limits the growth of plants. The primary way in which plants obtain nitrogen compounds they can use is with the help of bacteria that live in the soil.

Bacteria, called **nitrogen-fixing bacteria,** are able to convert the nitrogen gas (N_2) that enters the soil into ammonia that plants can use. Certain kinds of these bacteria live freely in the soil and are called **free-living nitrogen-fixing bacteria.** Others, known as **symbiotic nitrogen-fixing bacteria,** have a mutualistic relationship with certain plants and live in nodules in the roots of plants known as legumes (peas, beans, and clover) and certain trees such as alders. Some grasses and evergreen trees appear to have a similar relationship with certain root fungi that seem to improve the nitrogen-fixing capacity of the plant.

2. The Role of Producers and Consumers Once plants and other producers have nitrogen available in a form they can use, they can construct proteins, DNA, and other important nitrogen-containing organic molecules. When herbivores eat plants, the plant protein molecules are broken down to smaller building blocks called amino acids. These amino acids are then reassembled to form proteins typical for the herbivore. This same process is repeated throughout the food chain.

3. The Role of Decomposers and Other Bacteria Bacteria and other types of decay organisms are involved in the nitrogen cycle also. Dead organisms and their waste products contain molecules, such as proteins, urea, and uric acid, that contain nitrogen. Decomposers break down these nitrogen-containing organic molecules, releasing ammonia, which can be used directly by many kinds of plants. Still other kinds of soil bacteria called **nitrifying bacteria** are able to convert ammonia to nitrite, which can be converted to nitrate. Plants can use nitrate as a source of nitrogen for synthesis of nitrogen-containing organic molecules.

Finally, bacteria known as **denitrifying bacteria** are, under conditions where oxygen is absent, able to convert nitrite to nitrogen gas (N_2), which is ultimately released into the atmosphere. These nitrogen atoms can reenter the cycle with the aid of nitrogen-fixing bacteria. (See figure 5.30.)

4. Unique Features of the Nitrogen Cycle Although a cyclic pattern is present in both the carbon cycle and the nitrogen cycle, the nitrogen cycle shows two significant differences. First, most of the difficult chemical conversions are made by bacteria and other microorganisms. Without the activities of bacteria, little nitrogen would be available and the world would be a very different place. Second, although nitrogen enters organisms by way of nitrogen-fixing bacteria and returns to the atmosphere through the actions of denitrifying bacteria, there is a secondary loop in the cycle that recycles nitrogen compounds directly from dead organisms and wastes directly back to producers.

5. Agriculture and the Nitrogen Cycle In naturally occurring soil, nitrogen is often a limiting factor for plant growth. To increase yields, farmers provide extra sources of nitrogen in several ways. Inorganic fertilizers are a primary method of increasing the nitrogen available. These fertilizers may contain ammonia, nitrate, or both.

Since the manufacture of nitrogen fertilizer requires a large amount of energy and uses natural gas as a raw material, fertilizer is expensive. Therefore, farmers use alternative methods to supply nitrogen and reduce their cost of production. Several different techniques are effective. Farmers can alternate nitrogen-yielding crops such as soybeans with nitrogen-demanding crops such as corn. Since soybeans are legumes that have symbiotic nitrogen-fixing bacteria in their roots, if soybeans are planted one year, the excess nitrogen left in the soil can be used by the corn plants grown the next year. Some farmers even plant alternating strips of soybeans and corn in the same field. A slightly different technique involves growing a nitrogen-fixing crop for a short period of time and then plowing the crop into the soil and letting the organic matter decompose. The ammonia released by decomposition serves as fertilizer to the crop that follows. This is often referred to as green manure. Farmers can also add nitrogen to the soil by spreading manure from animal production operations or dairy farms on the field and relying on the soil bacteria to decompose the organic matter and release the nitrogen for plant use.

Phosphorus Cycle

Phosphorus is another element common in the structure of living things. It is present in many important biological molecules such as DNA and in the membrane structure of cells. In addition, the bones and teeth of animals contain significant quantities of phosphorus.

The phosphorus cycle differs from the carbon and nitrogen cycles in one important respect. Phosphorus is not present in the atmosphere as a gas. The ultimate source of phosphorus atoms is rock. In nature, new phosphorus compounds are released by the erosion of rock and become dissolved in water. Plants use the dissolved phosphorus compounds to construct the molecules they need. Animals obtain the phosphorus they need when they consume plants or other animals. When an organism dies or excretes waste products, decomposer organisms recycle the phosphorus compounds back into the soil. Phosphorus compounds that are dissolved in water are ultimately precipitated as

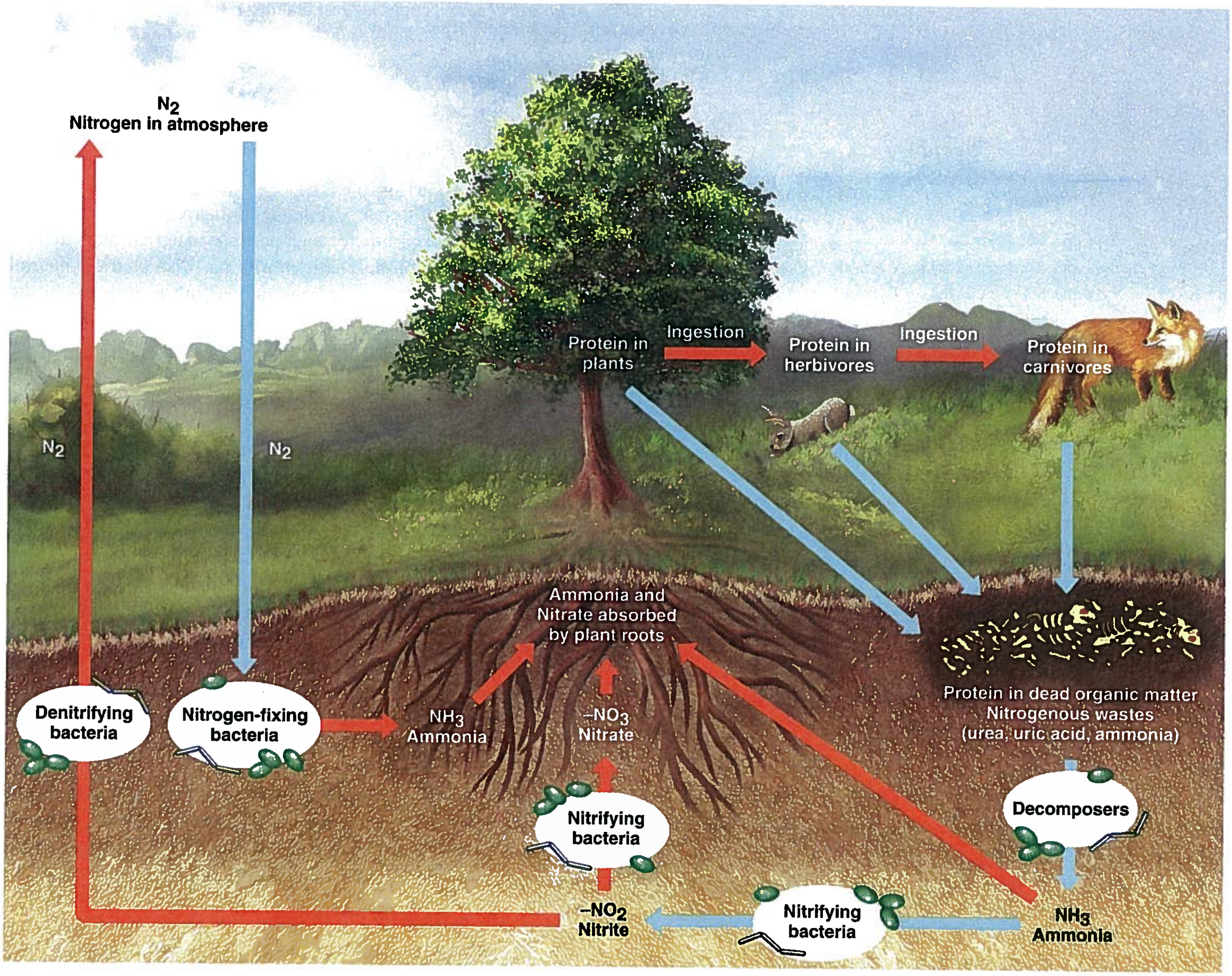


FIGURE 5.30 **Nitrogen Cycle** Nitrogen atoms are cycled in ecosystems. Atmospheric nitrogen is converted by nitrogen-fixing bacteria to a form that plants can use to make protein and other compounds. Proteins are passed to other organisms when one organism is eaten by another. Dead organisms and waste products are acted on by decay organisms to form ammonia, which may be reused by plants or converted to other nitrogen compounds by other kinds of bacteria. Denitrifying bacteria are able to convert inorganic nitrogen compounds into atmospheric nitrogen.

deposits. Geologic processes elevate these deposits and expose them to erosion, thus making these deposits available to organisms. Waste products of animals often have significant amounts of phosphorus. (See figure 5.31).

In places where large numbers of seabirds or bats congregate for hundreds of years, the thickness of their droppings (called guano) can be a significant source of phosphorus for fertilizer. (See Issues & Analysis, page 106.) In many soils and in aquatic ecosystems, phosphorus is a limiting factor and must be provided to crop plants to get maximum yields. Since phosphorus compounds come from rock, mining of phosphate-containing rock is necessary to provide the phosphate for fertilizer.

Human Impact on Nutrient Cycles

To appreciate how ecosystems function, it is important to have an understanding of how elements such as carbon, nitrogen, and phosphorus flow through them. When we look at these cycles from a global perspective, it is apparent that humans have significantly altered them in many ways.

Burning of Fossil Fuels

Fossil fuels (coal, oil, and natural gas) are carbon-containing molecules produced when organisms were fossilized. Thus these carbon-containing materials have been in long-term storage for millions

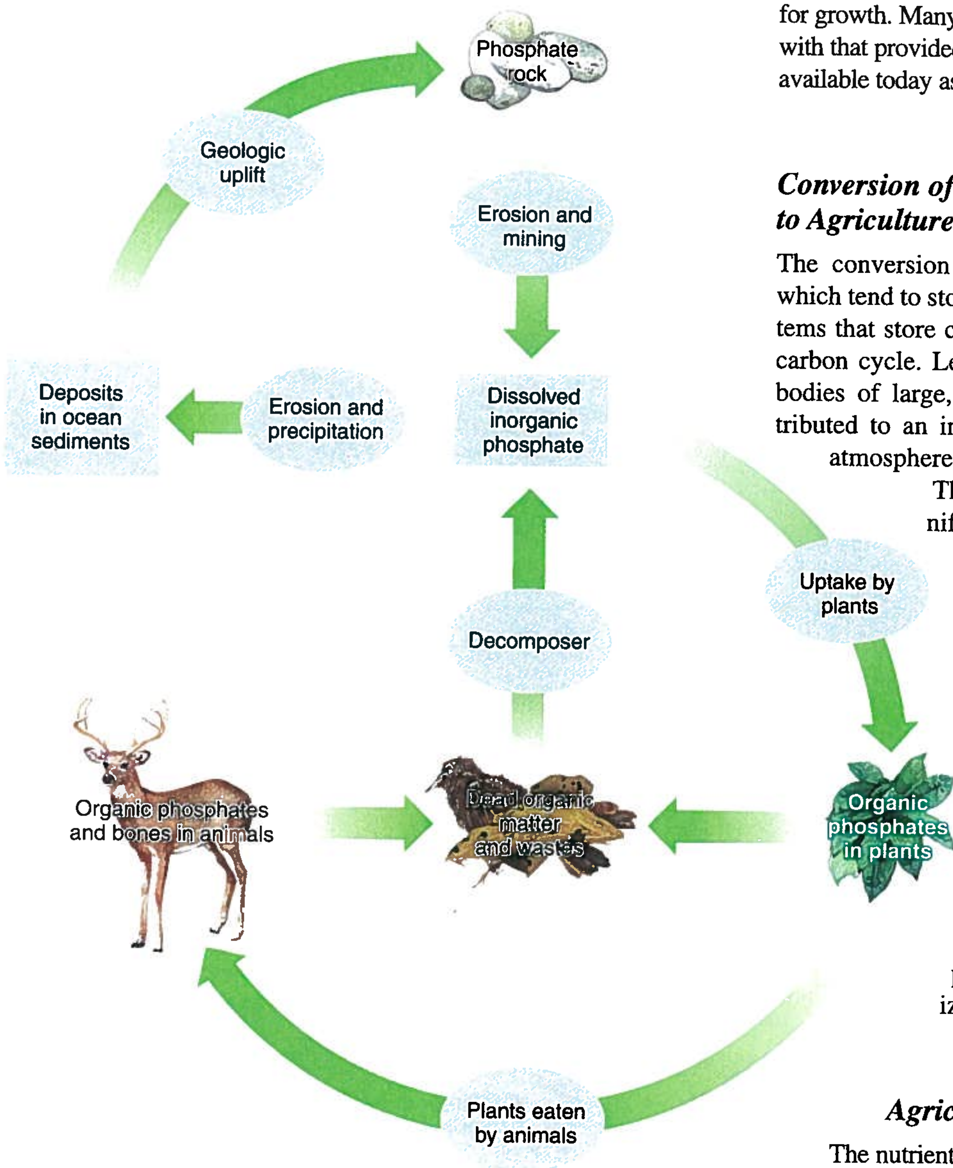


FIGURE 5.31 **Phosphorus Cycle** The source of phosphorus is rock that, when dissolved, provides the phosphate used by plants and animals.

of years. Burning fossil fuels releases large amounts of carbon dioxide into the atmosphere.

One consequence of these actions is that the amount of carbon dioxide in the atmosphere has been increasing steadily since humans began to use fossil fuels extensively. It has become clear that increasing carbon dioxide is causing changes in the climate of the world, and many nations are seeking to reduce energy use and prevent deforestation to minimize the increase in carbon dioxide in the atmosphere. This topic will be discussed in more detail in chapter 16, which deals with air pollution.

The burning of fossil fuels has also altered the nitrogen cycle. When fossil fuels are burned, the oxygen and nitrogen in the air are heated to high temperatures and a variety of nitrogen-containing compounds are produced. These compounds are used by plants as nutrients for growth. Many people suggest that these sources of nitrogen, along with that provided by fertilizers, have doubled the amount of nitrogen available today as compared to preindustrial times.

Conversion of Natural Ecosystems to Agriculture

The conversion of forest, wetland, and grassland ecosystems, which tend to store carbon for long periods, to agricultural ecosystems that store carbon only temporarily has disrupted the natural carbon cycle. Less carbon is being stored in the soil and in the bodies of large, long-lived plants such as trees. This has contributed to an increase in the amount of carbon dioxide in the atmosphere, which is tied to global climate change.

The use of fertilizer to increase crop yields has significantly altered several nutrient cycles. Fertilizers usually contain nitrogen, phosphorus, and potassium compounds. The numbers on a fertilizer bag indicate the percentage of each in the fertilizer. For example, a 6–24–24 fertilizer has 6 percent nitrogen, 24 percent phosphorus, and 24 percent potassium compounds. In addition to carbon, nitrogen, and phosphorus, potassium and other elements are cycled within ecosystems. In an agricultural ecosystem, these elements are removed when the crop is harvested. Therefore, farmers must not only return the nitrogen, phosphorus, and potassium, they must also analyze for other less prominent elements and add them to their fertilizer mixture as well.

Agricultural Runoff

The nutrients in fertilizers are intended to become incorporated into the bodies of the plants and animals that we raise for food. However, if too much nitrogen or phosphorus is applied as fertilizer or if they are applied at the wrong time, much of this fertilizer is carried into aquatic ecosystems.

In addition, raising large numbers of animals for food in concentrated settings results in huge amounts of animal wastes that contain nitrogen and phosphorus compounds that often enter local water sources. This addition of nitrogen and phosphorus to aquatic ecosystems is particularly significant since aquatic ecosystems normally are starved for these nutrients.

The presence of large amounts of these nutrients in either freshwater or saltwater results in increased rates of growth of bacteria, algae, and aquatic plants. Increases in the number of these organisms can have many different effects. Many algae are toxic, and when their numbers increase significantly, fish are killed and incidents of human poisoning occur. An increase in the number of plants and algae in aquatic ecosystems also can lead to low oxygen concentrations in the water. When these organisms die, decomposers use oxygen from the water as they break down the dead organic matter. This lowers the oxygen concentration, and many organisms die.

Going Green

Phosphorus-Free Lawn Fertilizer

Many lakes and streams experience extreme growth of algae and aquatic plants during the warm summer months. The presence of large amounts of vegetation in water interferes with boating, fishing, swimming, and other recreational activities. Some cyanobacteria (microscopic blue-green bacteria) actually produce toxic compounds that can sicken and kill. Human exposure to such toxins usually results in mild symptoms—skin rash, hay fever-like symptoms, or gastrointestinal upset. However, poisonings leading to deaths of pets, livestock, and wildlife are common when the animals drink water from lakes or streams that contain toxic cyanobacteria.

Excessive growth of aquatic plants and algae is stimulated by the warm water and abundant supplies of nutrients—particularly phosphorus. This has led many communities that have close ties to ocean, lakes, or streams to consider regulations on the use of phosphorus in lawn fertilizer. In 2002, Minnesota became the first state to regulate the use of phosphorus in lawn fertilizer. The law is predicated on the fact that soil tests in the state show that nearly all soils have adequate phosphorus and additional phosphorus in fertilizer is not needed. Excess phosphorus is not taken up by plants and much of it runs off into streams and lakes where it stimulates the growth of plants and algae. The regulations prohibit or severely restrict the use of phosphorus in lawn fertilizers. Exceptions are made for newly established lawns, which can use phosphorus-containing fertilizer during the first year of growth or places where soil tests show low phosphorus. The lawn-care industry responded immediately by producing phosphorus-free lawn fertilizer.

Summary

Everything that affects an organism during its lifetime is collectively known as its environment. The environment of an organism can be divided into biotic (living) and abiotic (nonliving) components.

The space an organism occupies is known as its habitat, and the role it plays in its environment is known as its niche. The niche of a species is the result of natural selection directing the adaptation of the species to a specific set of environmental conditions.

Organisms interact with one another in a variety of ways. Predators kill and eat prey. Organisms that have the same needs compete with one another and do mutual harm, but one is usually harmed less and survives. Symbiotic relationships are those in which organisms live in physical contact with one another. Parasites live in or on another organism and derive benefit from the relationship, harming the host in the process. Commensal organisms derive benefit from another organism but do not harm the host. Mutualistic organisms both derive benefit from their relationship.

A community is the biotic portion of an ecosystem that is a set of interacting populations of organisms. Those organisms and their abiotic environment constitute an ecosystem. In an ecosystem, energy is trapped by producers and flows from producers through various trophic levels of consumers (herbivores, carnivores, omnivores, and decomposers). About 90 percent of the energy is lost as it passes from one trophic level to the next. This means that the amount of biomass at higher trophic levels is usually much less than that at lower trophic levels. The sequence of organisms through which energy flows is known as a food chain. Several interconnecting food chains constitute a food web.

The flow of atoms through an ecosystem involves all the organisms in the community. The carbon, nitrogen, and phosphorus cycles are examples of how these materials are cycled in ecosystems.

ISSUES & ANALYSIS

Phosphate Mining in Nauru

The 21-km^2 island of Nauru, located in a remote corner of the Pacific Ocean, has been devastated by 90 years of phosphate mining. The environmental damage to the island has created financial, legal, and cultural problems for the islanders. The phosphate deposits found on Nauru and a few other Pacific islands are a combination of limestone and guano. The limestone is coral that forms the substrate of the island and the guano is the droppings from nesting seabirds that have accumulated for thousands of years. Nauru's phosphate is the only resource with which the island can sustain an economy. Nauru produces about 2 million metric tons of phosphate per year. Most of this is exported to Australia, where it is used as fertilizer.

Phosphate mining on Nauru generally occurs in the interior of the island. The mining activity has stripped away the soil and vegetation. Eighty percent of the island is a barren wasteland. The lack of vegetation has changed the climate. The island is now hotter and the rising hot air prevents rain clouds from settling over the island. This contributes to frequent droughts on the island.

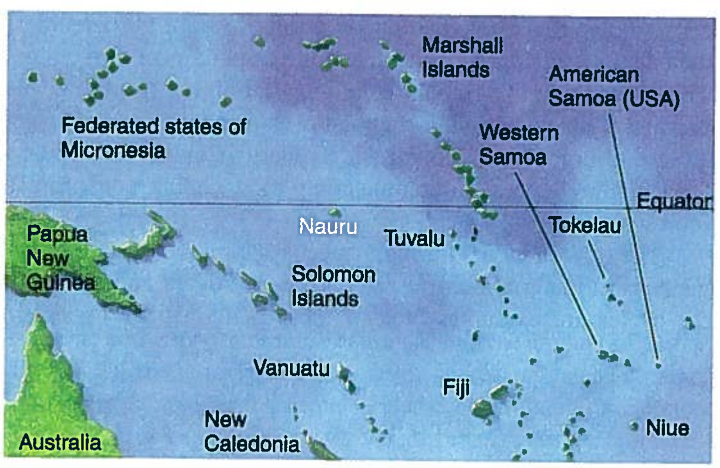
Because of the lack of soil and vegetation in the interior, any agriculture is limited to a narrow band near the shore. The Nauruans cannot raise enough food to sustain the population. Their traditional diet has been replaced with imported foods. The change in diet has led to an increase in the occurrence of high blood pressure, diabetes, and obesity. These problems have led to a decrease in the life expectancy of the islanders, which is about 50 years for men and 55 years for women.

Nauru's problems are becoming increasingly acute, as the phosphate on the island has been nearly exhausted and mining has virtually ceased. Thus, the government of Nauru is looking into the question of responsibility for the ecological disaster and is seeking ways to rehabilitate the island.

The Nauruans live on a strip of land along the coast, and with the population expanding, they need more living space. The population has increased from 2000 in 1968 to over 9000 by 2008. What the island also needs is new construction, most notably a hospital, schools, and government buildings. This development can only occur in the central part of the island, which is currently a wasteland of limestone and coral.

Several ideas have been discussed regarding the future of the island. Creating an area for agriculture is paramount. In order to be self-sufficient, the islanders must also consider a water filteration system, fish and pig farms, and tree plantations on an island with little remaining soil. One solution is to level the mined area and import topsoil, humus, and other nutrients, thus beginning the long process of rebuilding the ecosystem. This would be very expensive and could take more than 30 years. Another option is more drastic. It calls for the total removal of the population to another island. This solution is being considered because the present island of Nauru is so damaged, and there are no economically viable enterprises to replace the nearly exhausted phosphate mine. There is 50 percent unemployment. This rather hopeless situation leads many to believe that evacuating the Nauruans to some other Pacific island is the only choice.

- Do you think the island can be rehabilitated?
- Should the countries that benefited from the phosphate mining be expected to rehabilitate the island?
- Since the cost of rehabilitating the island would be huge, is evacuating the island the only viable option?



Phosphate mine

Islanders at a public meeting

Thinking Green

1. Purchase detergents that do not contain phosphorus (phosphate).
2. Compost food waste—do not use the garbage disposal.
3. Reduce the amount of carbon dioxide you produce by reducing energy consumption.
4. Choose local, native plants for landscaping.
5. Reduce or eliminate the amount of yard planted to grass.
6. Provide habitat for wildlife with plantings that provide food or shelter.
7. Do not use fertilizer or pesticides on our lawn.

What's Your Take?

In the United States about $20 billion is spent each year on the care of lawns and gardens. A significant amount of this cost involves the use of fertilizer to stimulate the growth of grass. Fertilizer runoff from lawns is a significant water pollution problem. Although most lawns will grow without fertilizer, the quality of the lawn is often not as nice. It is often possible to substitute groundcovers or natural landscaping for lawns.

Should people maintain grass lawns? Choose one side of the question and develop arguments that support your position.

Review Questions

1. Define *environment.*
2. Describe, in detail, the niche of a human.
3. How is natural selection related to the concept of niche?
4. List five predators and their prey organisms.
5. How is an ecosystem different from a community?
6. Humans raising cattle for food is what kind of relationship?
7. Give examples of organisms that are herbivores, carnivores, and omnivores.
8. What are some different trophic levels in an ecosystem?
9. Describe the carbon cycle, the nitrogen cycle, and the phosphorus cycle.
10. Analyze an aquarium as an ecosystem. Identify the major abiotic and biotic factors. List members of the producer, primary consumer, secondary consumer, and decomposer trophic levels.

Critical Thinking Questions

1. Ecologists and political scientists look at habitat destruction differently. Consider the Case Study about habitat conservation plans and the political, economic, and scientific issues that surround conservation plans. Identify some perspectives each discipline has to contribute to our understanding of habitat destruction. What values does each place on the ideas of the other disciplines? What do you think about the issue of creating conservation plans? Protecting habitat from destruction? Why?
2. Even before humans entered the scene, many species of plants and animals were extinct and new ones had developed. Why are we even concerned about endangered species, given the fact that species have always come and gone?
3. Concentrations of industrial chemicals are high in some species of fish, high enough to call for an advisory to limit the number of fish a person should eat within a given period of time. Many of these chemicals are thought to cause cancer, but cancer is an effect that is often not felt for decades after exposure. How do scientists decide how many fish can be safely eaten? Is there any "safe" level? What evidence would convince you that there is danger? How could you tell?
4. You notice after using pesticides on your farm field that the number of insects declines for a year. The next year, though, they come back and you need to reapply the pesticide. This time, though, there is less of an effect on the insect population. A third application in another year has even less of an effect. What is your hypothesis about what is happening here? Design an experiment that tests your hypothesis.