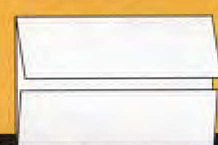
How Ecosystems Work

CHAPTER 5

PRE-READING ACTIVITY

FOLDNOTES

Double-Door Fold Before you read this chapter, create the **FoldNote** entitled "Double-Door Fold" described in the Reading and Study Skills section of the Appendix. Write "Energy flow in ecosystems" on one flap of the double door and "Movement of materials in ecosystems" on the other flap. As you read the chapter, compare the two topics, and write characteristics of each on the inside of the appropriate flap.



This green frog gets the energy it needs to survive by eating other organisms, such as dragonflies.

SECTION 1

Energy Flow in Ecosystems

Just as a car cannot run without fuel, an organism cannot survive without a constant supply of energy. Where does an organism's energy come from? The answer to that question depends on the organism, but the ultimate source of energy for almost all organisms is the sun.

Objectives

- Describe how energy is transferred from the sun to producers and then to consumers.
- Describe one way in which consumers depend on producers.
- List two types of consumers.
- Explain how energy transfer in a food web is more complex than energy transfer in a food chain.
- Explain why an energy pyramid is a representation of trophic levels.

Key Terms

photosynthesis
producer
consumer
decomposer
cellular respiration
food chain
food web
trophic level

Life Depends on the Sun

Energy from the sun enters an ecosystem when a plant uses sunlight to make sugar molecules by a process called **photosynthesis.** During photosynthesis, plants, algae, and some bacteria capture solar energy. Solar energy drives a series of chemical reactions that require carbon dioxide and water, as shown in **Figure 1.** The result of photosynthesis is the production of sugar molecules known as *carbohydrates*. Carbohydrates are energy-rich molecules which organisms use to carry out daily activities. As organisms consume food and use energy from carbohydrates, the energy travels from one organism to another. Plants, such as the sunflowers in **Figure 2,** produce carbohydrates in their leaves. When an animal eats a plant, some energy is transferred from the plant to the animal. Organisms use this energy to move, grow, and reproduce.

Figure 1 ▶ During photosynthesis, plants use carbon dioxide, water, and solar energy to make carbohydrates and oxygen.

Figure 2 ▶ The cells in the leaves of these sunflowers contain a green chemical called *chlorophyll*. Chlorophyll helps plants trap energy from the sun to produce energy-rich carbohydrates.

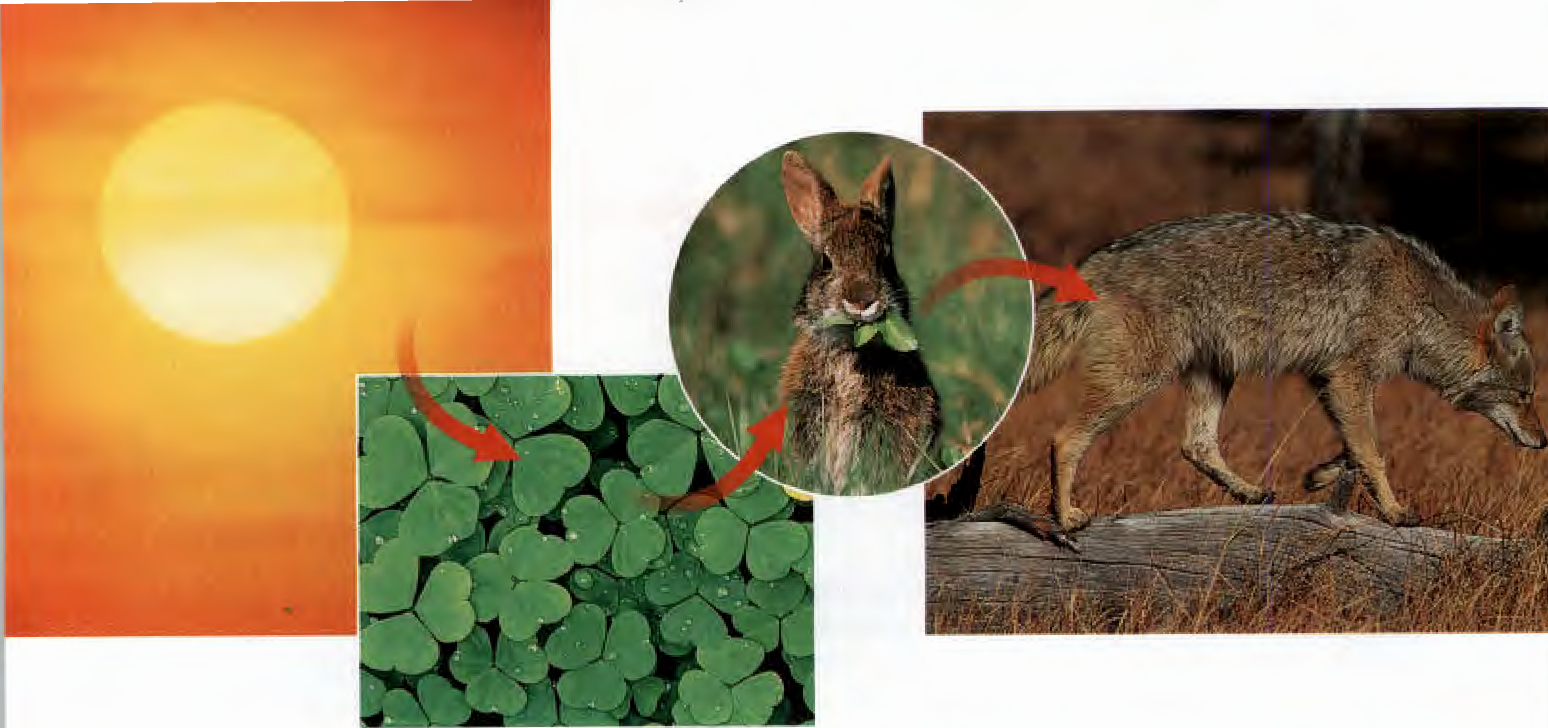


Figure 3 ▶ Transfer of Energy Almost all organisms depend on the sun for energy. Plants like the clover shown above get energy from the sun. Animals like the rabbit and coyote get their energy by eating other organisms.

From Producers to Consumers When a rabbit eats a clover plant, the rabbit gets energy from the carbohydrates the clover plant made through photosynthesis. If a coyote eats the rabbit, some of the energy is transferred from the rabbit to the coyote. In the example shown in **Figure 3,** the clover is the producer. A **producer** is an organism that makes its own food. Producers are also called *autotrophs,* self-feeders. Both the rabbit and the coyote are **consumers,** organisms that get their energy by eating other organisms. Consumers are also called *heterotrophs,* other-feeders. In the example shown in **Figure 3,** the clover, rabbit, and coyote get their energy from the sun. Some producers get energy directly from the sun by absorbing it through their leaves. Consumers get energy indirectly from the sun by eating producers or other consumers.

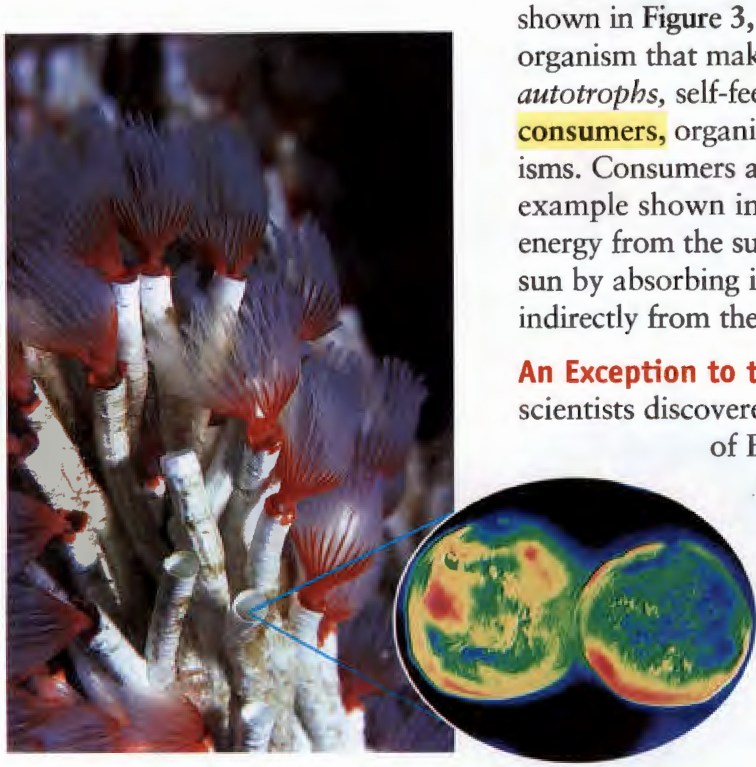


Figure 4 ▶ The tube worms (above) depend on bacteria that live inside them to survive. The bacteria (right) use energy from hydrogen sulfide to make their own food.

An Exception to the Rule: Deep-Ocean Ecosystems In 1977, scientists discovered areas on the bottom of the ocean off the coast of Ecuador that were teeming with life, even though sunlight did not reach the bottom of the ocean. The scientists found large communities of worms, clams, crabs, mussels, and barnacles living near thermal vents in the ocean floor. These deep-ocean communities exist in total darkness, where photosynthesis cannot occur. So where do these organisms get their energy? Bacteria, such as those pictured in **Figure 4,** live in some of these organisms and use hydrogen sulfide to make their own food. Hydrogen sulfide is present in the hot water that escapes from the cracks in the ocean floor. Therefore, the bacteria are producers that can make food without sunlight. These bacteria are eaten by the other underwater organisms and thus support a thriving ecosystem.

What Eats What

Table 1 below classifies organisms by the source of their energy. Consumers that eat only producers are called *herbivores*, or plant eaters. Rabbits are herbivores and so are cows, sheep, deer, grasshoppers, and many other animals. Consumers, such as lions and hawks, that eat only other consumers are called *carnivores*, or flesh eaters. You already know that humans are consumers, but what kind of consumers are we? Because most humans eat both plants and animals, we are called *omnivores*, or eaters of all. Bears, pigs, and cockroaches are other examples of omnivores. Some consumers get their food by breaking down dead organisms and are called **decomposers.** Bacteria and fungi are examples of decomposers. The decomposers allow the nutrients in the rotting material to return to the soil, water, and air.

MATHPRACTICE

A Meal Fit for a Grizzly Bear Grizzly bears are omnivores that can eat up to 15 percent of their body weight per day when eating salmon and up to 33 percent of their body weight when eating fruits and other vegetation. How many pounds of salmon can a 200 lb grizzly bear eat in one day? How many pounds of fruits and other vegetation can the same bear eat in one day?

Table 1 ▼

What Eats What in an Ecosystem		
	Energy source	**Examples**
Producer	makes its own food through photosynthesis or chemical sources	grasses, ferns, cactuses, flowering plants, trees, algae, and some bacteria
Consumer	gets energy by eating producers or other consumers	mice, starfish, elephants, turtles, humans, and ants
Types of Consumers in an Ecosystem		
	Energy source	**Examples**
Herbivore	producers	cows, sheep, deer, and grasshoppers
Carnivore	other consumers	lions, hawks, snakes, spiders, sharks, alligators, and whales
Omnivore	both producers and consumers	bears, pigs, gorillas, rats, raccoons, cockroaches, some insects, and humans
Decomposer	breaks down dead organisms in an ecosystem and returns nutrients to soil, water, and air	fungi and bacteria

Figure 5 ▶ Bears, such as the grizzly bear below, are omnivores. Grizzly bears eat other consumers, such as salmon, but they also eat various plants.

Connection to Chemistry

Chemical Equations Chemical reactions are represented by chemical equations. A chemical equation is a shorthand description of a chemical reaction using chemical formulas and symbols. The starting materials in a reaction are called *reactants*, and the substances formed from a reaction are called *products*. The number of atoms of each element in the reactants equals the number of atoms of those elements in the products to make a balanced equation.

Cellular Respiration: Burning the Fuel

So far, you have learned how organisms get energy. But how do they use the energy they get? To understand the process, use yourself as an example. Suppose you have just eaten a large meal. The food you ate contains a lot of energy. Your body gets the energy out of the food by using the oxygen you breathe to break down the food. By breaking down the food, your body obtains the energy stored in the food.

The process of breaking down food to yield energy is called **cellular respiration,** which occurs inside the cells of most organisms. This process is different from *respiration,* which is another name for breathing. During cellular respiration, cells absorb oxygen and use it to release energy from food. As you can see in **Figure 6,** the chemical equation for cellular respiration is essentially the reverse of the equation for photosynthesis. During cellular respiration, sugar and oxygen combine to yield carbon dioxide, water, and, most importantly, energy.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Figure 6 ► Through cellular respiration, cells use glucose and oxygen to produce carbon dioxide, water, and energy.

CASE STUDY

DDT in an Aquatic Food Chain

In the 1950s and 1960s, something strange was happening in the estuaries near Long Island Sound, near New York and Connecticut. Birds of prey, such as ospreys and eagles, that fed on fish in the estuaries had high concentrations of the pesticide DDT in their bodies. But when the water in the estuary was tested, it had low concentrations of DDT.

What accounted for the high levels of DDT in the birds? Poisons that dissolve in fat, such as DDT, can become more concentrated as they move up a food chain in a process called *biological magnification.* When the pesticide enters the water, algae and bacteria take in the poison. When fish eat the algae and bacteria, the poison dissolves into the fat of the fish rather than diffusing back into the water. Each time a bird feeds on a fish, the bird accumulates more DDT in its fatty tissues. In some estuaries on Long Island Sound, DDT concentrations in fatty tissues of organisms were magnified almost 10 million times from the bottom to the

► A high concentration of DDT decreases the thickness and the strength of eggshells of many birds of prey.

You use a part of the energy you obtained through cellular respiration to carry out your daily activities. Every time you walk, breathe, read a book, think, or play a sport, you use energy. The energy you obtain is also used to make more body tissues and to fight diseases so that you grow and stay healthy. Excess energy you obtain is stored as fat or sugar. All living things use cellular respiration to get the energy they need from food molecules. Even organisms that make their own food through photosynthesis use cellular respiration to obtain energy from the carbohydrates they produce.

Connection to Biology

Calories from Food The substances your body needs to survive and grow come from food. Carbohydrates, proteins, and fats are major sources of energy for the body. The energy content of food can be found by burning a dry food sample in a special calorimeter. Both carbohydrates and proteins provide 4 Calories (Cal) of energy per gram, while fats provide 9 Cal of energy per gram.

Energy Transfer

Each time one organism eats another organism, a transfer of energy occurs. We can trace the transfer of energy as it travels through an ecosystem by studying food chains, food webs, and trophic levels. Food chains, food webs, and trophic levels can tell us how energy is transferred as well as how much energy is transferred between organisms in an ecosystem. Studying the paths of energy between organisms can also tell us which organisms in an ecosystem depend on other organisms to survive.

▶ Poisons such as DDT have the greatest affect on organisms at the top of food chains. For example, the osprey shown here would have a greater concentration of DDT in its body than the perch it's about to eat.

top of the food chain. Large concentrations of DDT may kill an organism, weaken its immune system, cause deformities, or impair its ability to reproduce. DDT can also weaken the shells of bird eggs. When eggs break too soon, bird embryos die. Therefore, the effects of these chemicals cause a tremendous drop in the population of carnivorous bird species.

The U.S. government recognized DDT as an environmental contaminant and in 1972 banned its sale except in emergencies. The aquatic food chains immediately started to recover, and the populations of ospreys and eagles started to grow.

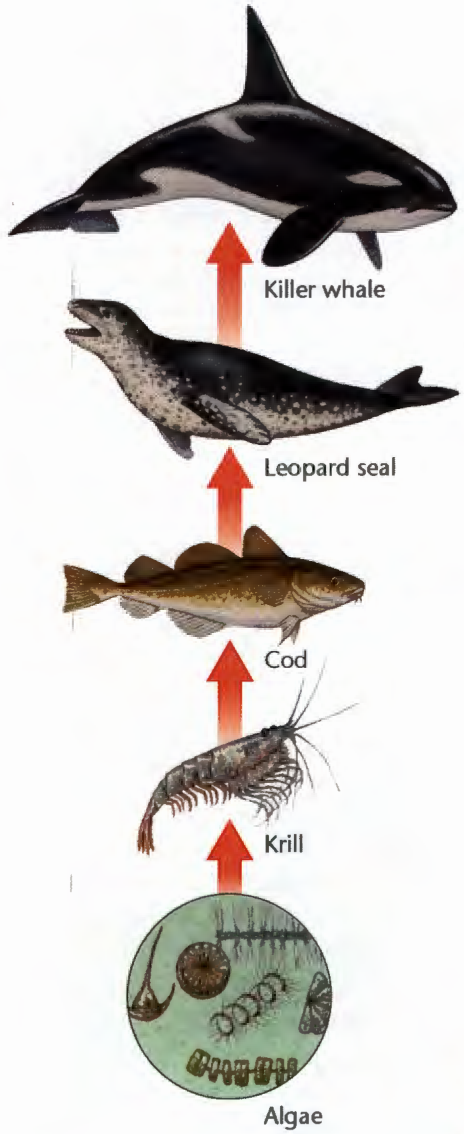
Food chains are still not free of DDT. DDT is still legal in some countries, where it is used in large quantities to eliminate mosquitoes that carry the disease malaria. As a result, migratory birds may be exposed to DDT while wintering in locations outside the United States.

CRITICAL THINKING

1. Analyzing Processes DDT does not dissolve readily in water. If it did, how would the accumulation of the pesticide in organisms be affected?

2. Evaluating Information Even though DDT is harmful to the environment, why is it still used in some countries?

Figure 7 ▶ Energy is transferred from one organism to another in a food chain, such as the one shown below. Algae are the producers in this ocean food chain.



Food Chains and Food Webs A food chain is a sequence in which energy is transferred from one organism to the next as each organism eats another organism. **Figure 7** shows a typical food chain in an ocean ecosystem. Algae are eaten by krill, which are eaten by cod. The cod are eaten by leopard seals, which are eaten by killer whales.

Energy flow in an ecosystem is much more complicated than energy flow in a simple food chain. Ecosystems almost always contain many more species than a single food chain contains. In addition, most organisms, including humans, eat more than one kind of food. So a food web, such as the one shown in **Figure 8**, includes more organisms and multiple food chains linked together. A food web shows many feeding relationships that are possible in an ecosystem. Notice that the food chain is just one strand in the larger food web.

Trophic Levels Each step in the transfer of energy through a food chain or food web in an ecosystem is known as a trophic level. In **Figure 8**, the algae are in the bottom trophic level, the krill are in the next level, and so on. Each time energy is transferred from one organism to another, some of the energy is lost as heat and less energy is available to organisms at the next trophic level. Some of this energy is lost during cellular respiration. Organisms use much of the remaining energy to carry out the functions of living, such as producing new cells, regulating body temperature, and moving

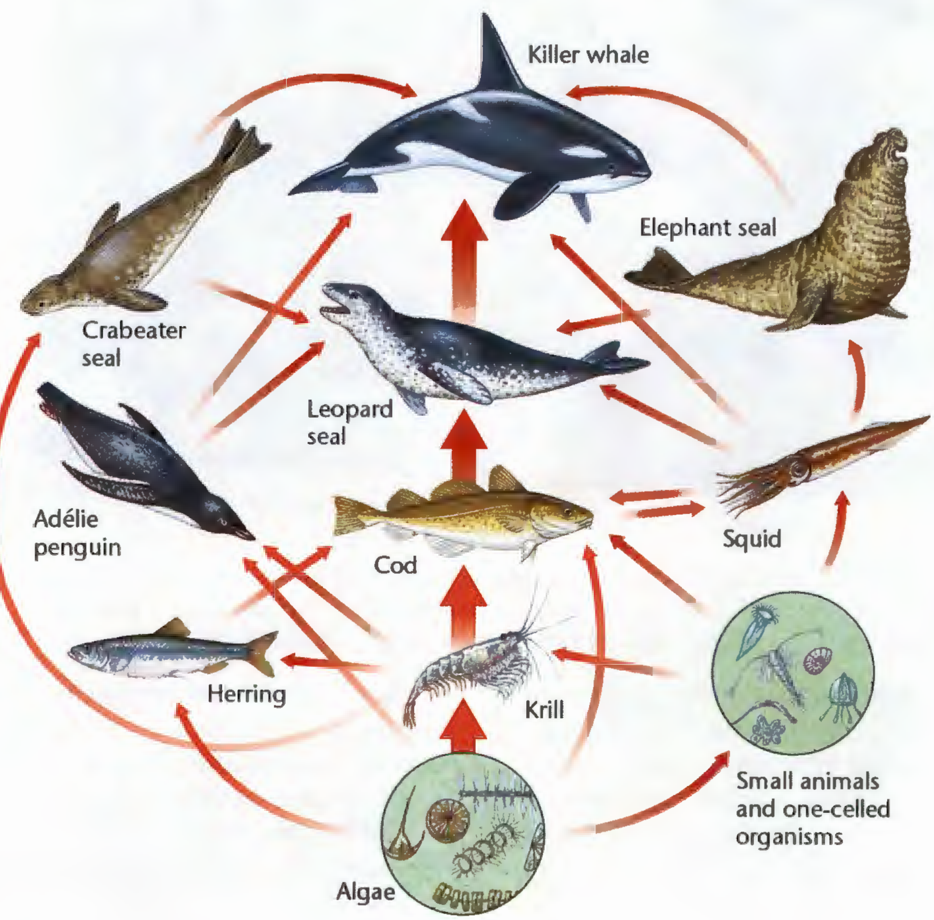
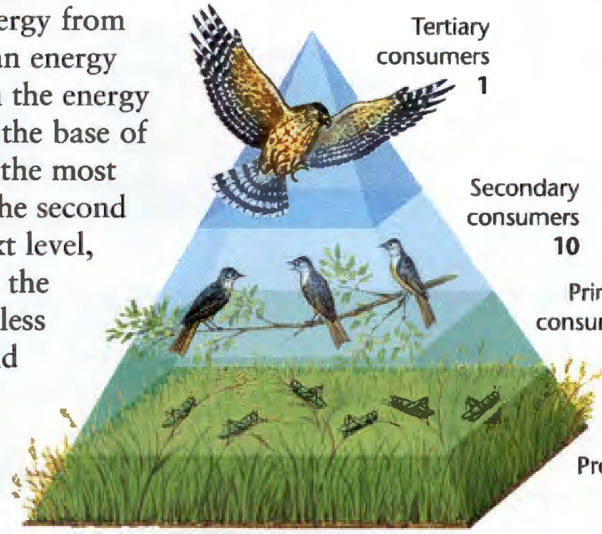


Figure 8 ▶ This food web shows how the largest organisms, such as a killer whale, depend on the smallest organisms, such as algae, in an ocean ecosystem.

around. About 90 percent of the energy at each trophic level is used in these ways. The remaining 10 percent of the energy becomes part of the organism's body and is stored in its molecules. This 10 percent that is stored is all that is available to the next trophic level when one organism consumes another organism.

Energy Pyramids One way to visualize the loss of energy from one trophic level to the next trophic level is to draw an energy pyramid like the one shown in **Figure 9**. Each layer in the energy pyramid represents one trophic level. Producers form the base of the pyramid, the lowest trophic level, which contains the most energy. Herbivores contain less energy and make up the second level. Carnivores that feed on herbivores form the next level, and carnivores that feed on other carnivores make up the top level. Organisms in the upper trophic levels store less energy than both herbivores and producers. A pyramid is a good way to illustrate trophic levels because the pyramid becomes smaller toward the top, where less energy is available.

Figure 9 ▶ This energy pyramid shows how energy is lost from one trophic level to the next. The grass at the bottom level stores 1,000 times more energy than the hawk at the top level.



How Energy Loss Affects an Ecosystem The decreased amount of energy at each trophic level affects the organization of an ecosystem. First, because so much energy is lost at each level, there are fewer organisms at the higher trophic levels. For example, zebras and other herbivores outnumber lions on the African savanna by about 1,000 to 1. In this example, there simply are not enough herbivores to support more carnivores.

Second, the loss of energy from trophic level to trophic level limits the number of trophic levels in an ecosystem. Ecosystems rarely have more than four or five trophic levels because the ecosystem does not have enough energy left to support higher levels. For example, a lion typically needs up to 250 km² of land to hunt for food. Therefore, an animal that feeds on lions would have to expend a lot of energy to harvest the small amount of energy available at the top trophic level. The organisms that do feed on organisms at the top trophic level are usually small, such as parasitic worms and fleas that require a very small amount of energy.

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Topic: Food Chains, Food Webs, and Trophic Levels
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SECTION 1 Review

1. **Describe** how energy is transferred from one organism to another.
2. **Describe** the role that producers play in an ecosystem.
3. **Explain** the difference between an herbivore and an omnivore.
4. **Compare** energy transfer in a food chain to energy transfer in a food web.

CRITICAL THINKING

5. **Interpreting Graphics** Look at Figure 8. What feeding relationships does the crabeater seal have?
6. **Inferring Relationships** Read the paragraph under the heading, "Trophic Levels" in this section. Could more people be supported by 20 acres of land if they ate only plants instead of both plants and animals? Explain your answer. READING SKILLS

SECTION 2

The Cycling of Materials

Objectives

- Describe the short-term and long-term process of the carbon cycle.
- Identify one way that humans are affecting the carbon cycle.
- List the three stages of the nitrogen cycle.
- Describe the role that nitrogen-fixing bacteria play in the nitrogen cycle.
- Explain how the excess use of fertilizer can affect the nitrogen and phosphorus cycles.

Key Terms

carbon cycle
nitrogen-fixing bacteria
nitrogen cycle
phosphorus cycle

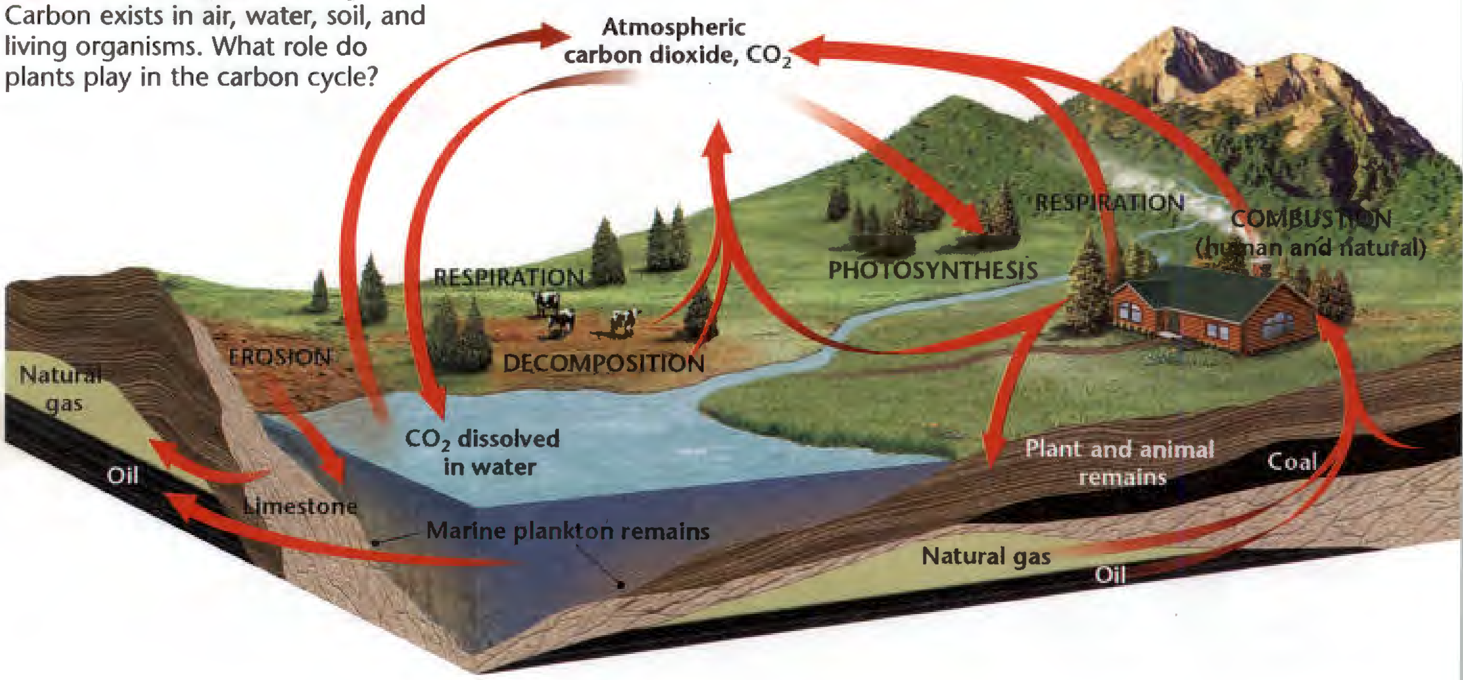
What will happen to the next ballpoint pen you buy? You will probably use it until its ink supply runs out and then throw it away. The plastic and steel the pen is made of will probably never be reused. By contrast, materials in ecosystems are constantly reused. In this section, you will read about three cycles by which materials are reused—the carbon cycle, the nitrogen cycle, and the phosphorus cycle.

The Carbon Cycle

Carbon is an essential component of proteins, fats, and carbohydrates, which make up all organisms. The carbon cycle is a process by which carbon is cycled between the atmosphere, land, water, and organisms. As shown in **Figure 10,** carbon enters a short-term cycle in an ecosystem when producers, such as plants, convert carbon dioxide in the atmosphere into carbohydrates during photosynthesis. When consumers eat producers, the consumers obtain carbon from the carbohydrates. As the consumers break down the food during cellular respiration, some of the carbon is released back into the atmosphere as carbon dioxide. Organisms that make their own food through photosynthesis also release carbon dioxide during cellular respiration.

Some carbon enters a long-term cycle. For example, carbon may be converted into *carbonates,* which make up the hard parts of bones and shells. Bones and shells do not break down easily.

Figure 10 ▶ The Carbon Cycle Carbon exists in air, water, soil, and living organisms. What role do plants play in the carbon cycle?



Over millions of years, carbonate deposits produce huge formations of limestone rocks. Limestone is one of the largest *carbon sinks,* or carbon reservoirs, on Earth.

Some carbohydrates in organisms are converted into fats, oils, and other molecules that store energy. The carbon in these molecules may be released into the soil or air after an organism dies. When these molecules are released they can form deposits of coal, oil, and natural gas underground known as *fossil fuels*. Fossil fuels are essentially stored carbon left over from bodies of plants and animals that died millions of years ago.

How Humans Affect the Carbon Cycle When we burn fossil fuels, we release carbon into the atmosphere. The carbon returns to the atmosphere as carbon dioxide. Cars, factories, and power plants rely on these fossil fuels to operate. In the year 2000, vehicles, such as the truck in **Figure 11,** were the source of one-third of all carbon dioxide emitted in the United States. All together, about 6 billion metric tons of carbon a year are released into the atmosphere as carbon dioxide. Natural burning of wood or forest fires combined with the burning of fossil fuels make up this 6 billion metric tons. About half of this carbon dioxide remains in the atmosphere, so over a period of years, the amount of carbon dioxide in the atmosphere has steadily increased.

Increased levels of carbon dioxide may contribute to global warming, which is an overall increase in the temperature of the Earth. What happens to the carbon dioxide that is not absorbed by the atmosphere? Scientists estimate that over a billion metric tons of carbon dioxide dissolves into the ocean, which is a carbon sink. Plants probably absorb the remaining carbon dioxide.

QuickLAB

Make Every Breath Count

Procedure

1. Pour **100 mL** of **water** from a **graduated cylinder** into a **250 mL beaker.** Add several drops of **bromthymol blue** to the beaker of water. Make sure you add enough to make the solution a dark blue color.
2. Exhale through a **straw** into the solution until the solution turns yellow. (CAUTION: Be sure not to inhale or ingest the solution.)
3. Pour the yellow solution into a large **test tube** that contains a **sprig of *Elodea*.**
4. **Stopper** the test tube, and place it in a sunny location.
5. Observe the solution in the test tube after 15 minutes.

Analysis

1. What do you think happened to the carbon dioxide that you exhaled into the solution? What effect do plants, such as the *Elodea,* have on the carbon cycle?

Connection to Biology

The Rise of Carbon Dioxide
In the past 150 years, more than 350 billion tons of carbon have been released into the air in the form of carbon dioxide. The concentration of carbon dioxide today has increased 30 percent since preindustrial times. If the present amount of carbon dioxide emission continues, this concentration will double by 2080. Many scientists speculate that as a result, Earth's temperature may rise by 3°C.

Figure 11 ▶ This truck releases carbon into the atmosphere when it burns fuel to operate.

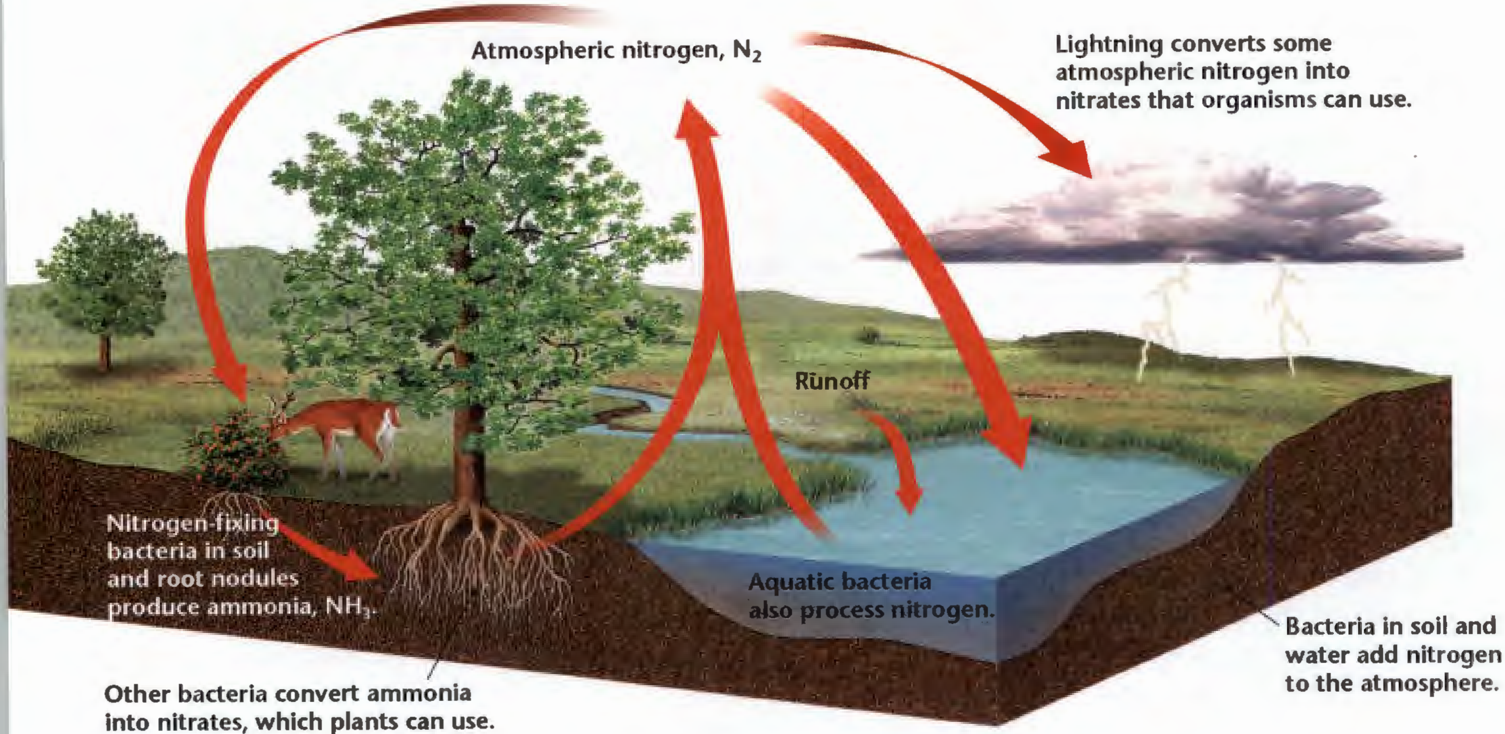


Figure 12 ▶ The Nitrogen Cycle Nitrogen could not be cycled in the atmosphere without nitrogen-fixing bacteria. What role do animals play in the nitrogen cycle?

Figure 13 ▶ The swellings on the roots of this soybean plant are called *nodules.* Nitrogen-fixing bacteria, as shown magnified at right, live inside the nodules of plants.

The Nitrogen Cycle

All organisms need nitrogen to build *proteins,* which are used to build new cells. Nitrogen makes up 78 percent of the gases in the atmosphere. However, most organisms cannot use atmospheric nitrogen. It must be altered, or fixed, before organisms can use it. The only organisms that can fix atmospheric nitrogen into chemical compounds are a few species of bacteria known as **nitrogen-fixing bacteria.** All other organisms depend upon these bacteria to supply nitrogen. Nitrogen-fixing bacteria are a crucial part of the **nitrogen cycle,** a process in which nitrogen is cycled between the atmosphere, bacteria, and other organisms. As shown in **Figure 12,** bacteria take nitrogen gas from the air and transform it into molecules that living things can use.

Nitrogen-fixing bacteria, shown in **Figure 13,** live within nodules on the roots of plants called *legumes.* Legumes include beans, peas, and clover. The bacteria use sugars provided by the legumes to produce nitrogen-containing compounds such as nitrates. The excess nitrogen fixed by the bacteria is released into the soil. In addition, some nitrogen-fixing bacteria live in the soil rather than inside the roots of legumes. Plants that do not have nitrogen-fixing bacteria in their roots get nitrogen from the soil. Animals get nitrogen by eating plants or other animals, both of which are sources of usable nitrogen.

Decomposers and the Nitrogen Cycle In the nitrogen cycle, nitrogen moves between the atmosphere and living things. After nitrogen cycles from the atmosphere to living things, nitrogen is again returned to the atmosphere with the help of bacteria. These decomposers are essential to the nitrogen cycle because they break down wastes, such as urine, dung, leaves, and other decaying plants and animals and return the nitrogen that these wastes and dead organisms contain to the soil. If decomposers did not exist, much of the nitrogen in ecosystems would be stored in wastes, corpses, and other parts of organisms. After decomposers return the nitrogen to the soil, bacteria transform a small amount of the nitrogen into nitrogen gas, which then returns to the atmosphere and completes the nitrogen cycle. So once nitrogen enters an ecosystem, most of it stays within the ecosystem, cycles between organisms and the soil, and is constantly reused.

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The Phosphorus Cycle

Phosphorus is an element that is a part of many molecules that make up the cells of living organisms. For example, phosphorus is an essential material needed to form bones and teeth in animals. Plants get the phosphorus they need from soil and water, while animals get their phosphorus by eating plants or other animals that have eaten plants. The **phosphorus cycle** is the movement of phosphorus from the environment to organisms and then back to the environment. This cycle is slow and does not normally occur in the atmosphere because phosphorus rarely occurs as a gas.

As shown in **Figure 14**, phosphorus may enter soil and water in a few ways. When rocks erode, small amounts of phosphorus dissolve as phosphate in soil and water. Plants absorb phosphates in the soil through their roots. In addition, phosphorus is added to soil and water when excess phosphorus is excreted in waste from organisms and when organisms die and decompose. Some phosphorus also washes off the land and eventually ends up in the ocean. Many phosphate salts are not soluble in water, so they sink to the bottom of the ocean and accumulate as sediment.

Geofact

Minerals in Your Mouth
Phosphorus is the 11th most abundant element in the Earth's crust and occurs naturally as phosphate in the mineral apatite. Apatite can exist in igneous, metamorphic, and sedimentary rocks as well as in your teeth and bones.

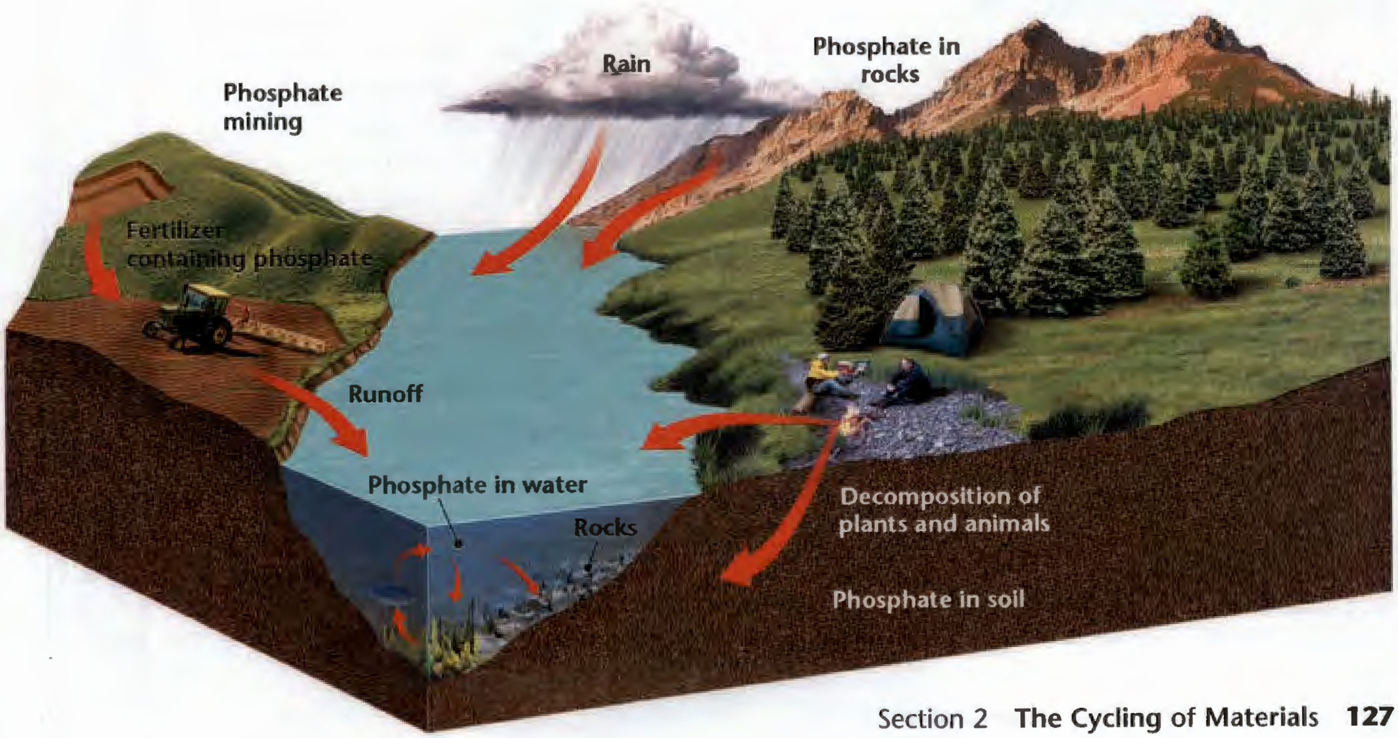
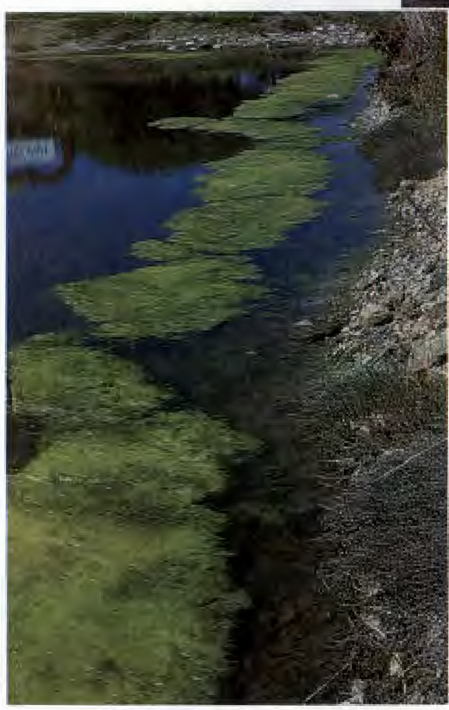


Figure 14 ▶ The Phosphorus Cycle Phosphorus moves from phosphate deposits in rock to the land, then to living organisms, and finally to the ocean.

Figure 15 ▶ More than 30 percent of fertilizer may flow with runoff from farmland into nearby waterways. Large amounts of fertilizer in water can cause an excessive growth of algae (below).



Fertilizers and the Nitrogen and Phosphorus Cycles People often apply fertilizers to stimulate and maximize plant growth. Fertilizers contain both nitrogen and phosphorus. The more nitrogen and phosphorus that is available to a plant, the faster and bigger the plant tends to grow. However, if excessive amounts of fertilizer are used, the fertilizer can enter terrestrial and aquatic ecosystems through runoff. Excess nitrogen and phosphorus in an aquatic ecosystem or nearby waterway can cause rapid and overabundant growth of algae, which results in an *algal bloom.* An algal bloom, as shown in Figure 15, is a dense, visible patch of algae that occurs near the surface of water. Algal blooms, along with other plants and the bacteria that break down dead algae, can deplete an aquatic ecosystem of important nutrients such as oxygen. Fish and other aquatic organisms need oxygen to survive.

Acid Precipitation We affect the nitrogen cycle every time we burn coal, wood, or oil. When we burn fuel, a large amount of nitric oxide is released into the atmosphere. Nitric oxide is a harmful gas, and when it is released into the air, it can combine with oxygen and water vapor to form nitric acid. Nitric acid can dissolve in rain and snow, which contributes to acid precipitation.

SECTION 2 Review

1. **Describe** the two processes of the carbon cycle.
2. **Describe** how the burning of fossil fuels affects the carbon cycle.
3. **Explain** how the excess use of fertilizer affects the nitrogen cycle and the phosphorus cycle.
4. **Explain** why the phosphorus cycle occurs more slowly than both the carbon cycle and the nitrogen cycle.

CRITICAL THINKING

5. **Making Comparisons** Write a short paragraph that describes the importance of bacteria in the carbon, nitrogen, and phosphorus cycles. What role does bacteria play in each cycle? WRITING SKILLS
6. **Applying Ideas** What is one way that a person can help reduce the level of carbon dioxide in the atmosphere? Can you think of more than one way?

SECTION 3

How Ecosystems Change

Ecosystems are constantly changing. A forest hundreds of years old may have been a shallow lake a thousand years ago. A dead tree falls to the ground and lets sunlight reach the forest floor. The sunlight causes some seeds to germinate, and soon wildflowers and shrubs cover the forest floor. Mosses, shrubs, and small trees cover the concrete of a demolished city building. These are all examples of environmental change that scientists define as ecological succession.

Objectives

- List two examples of ecological succession.
- Explain how a pioneer species contributes to ecological succession.
- Explain what happens during old-field succession.
- Describe how lichens contribute to primary succession.

Key Terms

ecological succession
primary succession
secondary succession
pioneer species
climax community

Ecological Succession

Ecological succession is a gradual process of change and replacement of the types of species in a community. In nature, the process of ecological succession may take hundreds or thousands of years. Each new community that arises often makes it harder for the previous community to survive. For example, the younger beech trees in **Figure 16** will have a hard time competing with the older beech trees for sun. However, if a shade-loving species of tree began to grow in the forest, the new species might replace the smaller beech trees.

Primary succession is a type of succession that occurs on a surface where no ecosystem existed before. Primary succession can occur on rocks, cliffs, and sand dunes. **Secondary succession**, the more common type of succession, occurs on a surface where an ecosystem has previously existed. Secondary succession occurs in ecosystems that have been disturbed or disrupted by humans, animals, or by natural processes such as storms, floods, earthquakes, and volcanoes.

Graphic Organizer **Chain-of-Events Chart**

Create the **Graphic Organizer** entitled "Chain-of-Events Chart" described in the Appendix. Then, fill in the chart with details about each step of ecological succession.

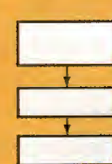


Figure 16 ▶ Taller beech trees compete with shorter, young beech trees for sun and make it hard for the younger trees to survive.

Figure 17 ▶ When Mount St. Helens erupted in 1980, much of the forest around the volcano was destroyed.

Secondary Succession In 1980, the volcano Mount St. Helens erupted in Washington State. The eruption at Mount St. Helens has been described as one of the worst volcanic disasters because more than 44,460 acres of forest were burned and flattened by the force of hot ash and other volcanic debris, as shown in **Figure 17.** After the eruption, plants began to colonize the volcanic debris. Such plants are called **pioneer species**—the first organisms to colonize any newly available area and begin the process of ecological succession. Over time, pioneer species will make the new area habitable for other species. If you visited Mount St. Helens today, you would find that the forest is in the process of secondary succession. **Figure 18** shows how after 12 years, plants and flowers had covered most of the lava and new trees and shrubs had started to grow. If these organisms at Mount St. Helens continue to grow, over time they will eventually form a climax community. A **climax community** is

CASE STUDY

Communities Maintained by Fire

Fires set by lightning or human activities occasionally sweep through large areas. Burned areas undergo secondary succession. In the forests of the Rocky Mountains, for example, burned areas are rapidly colonized by fireweed, which clothes the slopes with purple flowers. In some places, fire determines the nature of the climax community. In the United States, ecological communities that are maintained by fire include the chaparral of California, the temperate grassland of the Midwest, and many southern and western pine forests.

Plants native to these communities are adapted to living with fire. A wildfire that is not unusually hot may not harm fire-adapted pine trees, but it can kill deciduous trees—those trees that lose their leaves in winter. Seeds of some species, such as longleaf pine trees, will not germinate until exposed to temperatures of several hundred degrees. When a fire sweeps through a forest, the fire kills plants on the ground and stimulates the pine seeds to germinate.

▶ **Fireweed** is one type of plant that colonizes land after the land has been burned by fire.

Longleaf pines have a strange growth pattern. When they are young, they have long needles that reach down to the ground, and the trees remain only approximately a half of a meter high for many years, while they store nutrients. If a fire occurs, it sweeps through the tops of the tall trees that survived the last fire and the young longleaf pines near the ground may escape the fire. Then, the young pines use their stored food to grow very rapidly. A young pine can grow as much as 2 m/y. Soon the young pines are tall enough so that a fire near the ground would not harm them.

If regular fires are prevented in a fire-adapted community, deciduous trees may invade the area. These trees form a thick barrier near the ground. In addition, their dead leaves and a final and stable community. Even though a climax community continues to change in small ways, this type of community may remain the same through time if it is not disturbed.

Fire and Secondary Succession Natural fires caused by lightning are a necessary part of secondary succession in some communities, as discussed in the Case Study below. Some species of trees, such as the Jack pine, can release their seeds only after they have been exposed to the intense heat of a fire. Minor forest fires remove accumulations of brush and deadwood that would otherwise contribute to major fires that burn out of control. Some animal species also depend on occasional fires because they feed on the vegetation that sprouts after a fire has cleared the land. Therefore, foresters sometimes allow natural fires to burn unless the fires are a threat to human life or property.

Figure 18 ▶ The photo above was taken 12 years after the eruption of Mount St. Helens and shows evidence of secondary succession.

▶ These young lodgepole pine trees have started growing after a devastating forest fire.

▶ This firefighter is helping maintain a controlled fire in South Dakota. Some fires are set on purpose by fire officials to bring nutrients to soil from burned vegetation.

branches pile up on the ground and form extra fuel for fires. When a fire does occur, it is hotter and more severe than usual. The fire destroys not only the deciduous trees but also the pines. It may end up as a devastating wildfire.

Although it may seem odd, frequent burning is essential to preserve many plant communities and the animals that depend on them. This is the reason the U.S. Park Service adopted the policy of letting fires in national parks burn if they do not endanger human life or property.

This policy caused a public outcry when fires burned Yellowstone National Park in 1988, because people did not understand the ecology of fire-adapted communities. The fires later became an opportunity for visitors to learn about the changes in an ecosystem after a fire.

CRITICAL THINKING

1. Understanding Processes Explain how a longleaf pine tree might be more likely to survive a forest fire than a deciduous tree, such as a maple or oak tree.

2. Understanding Concepts Why must controlled fires be set in some ecosystems? What are the advantages? What are the disadvantages?

Figure 19 ▶ The illustration above shows what an abandoned farm area might look like during old-field succession. Why do you think young oak trees begin to appear around year 20?

Old-field Succession Another example of secondary succession is *old-field succession,* which occurs when farmland is abandoned. When a farmer stops cultivating a field, grasses and weeds quickly grow and cover the abandoned land. The pioneer grasses and weeds grow rapidly and produce many seeds to cover large areas.

Then over time, taller plants, such as perennial grasses, grow in the area. These plants shade the ground, which keeps light from the shorter pioneer plants. The long roots of the taller plants also absorb most of the water in the soil and deprive the pioneer plants of adequate water to survive. The pioneer plants soon die from lack of sunlight and water. As succession continues, the taller plants are deprived of light and water by growing trees. Finally, slower-growing trees, such as oaks, hickories, beeches, and maples, take over the area and block out the sunlight to the smaller trees. As shown in **Figure 19**, after about a century, the land can return to the climax community that existed before the farmers cleared it to plant crops.

Primary Succession On new islands created by volcanic eruptions, in areas exposed when a glacier retreats, or on any other surface that has not previously supported life, primary succession can occur. Primary succession is much slower than secondary succession because primary succession begins where there is no soil. It can take several hundred to several thousand years to produce fertile soil naturally. Imagine that a glacier melts and exposes an area of bare rock. The first pioneer species to colonize the bare rock will probably be bacteria and lichens, which can live without soil. Lichens, as shown in **Figure 20**, are important early pioneers in primary

FIELD ACTIVITY

Investigating Succession
Explore two or three blocks in your neighborhood, and find evidence of succession. Make notes in your ***EcoLog*** about the location and the evidence of succession that you observe. Pay attention to sidewalks, curbs, streets, vacant lots, and buildings, as well as parks, gardens, fields, and other open areas. Create a map from your data that identifies where succession is taking place in your neighborhood.

succession. They are the colorful, flaky patches that you see on trees and rocks. A lichen is a producer that is actually composed of two different species, a fungus and an alga. The alga photosynthesizes, while the fungus absorbs nutrients from rocks and holds water. Together, they begin to break down the rock.

As the growth of the lichen breaks down the rock, water may freeze and thaw in cracks, which breaks up the rock further. Soil slowly accumulates as dust particles in the air are trapped in cracks in the rock. Dead remains of lichens and bacteria also accumulate in the cracks. Mosses may later grow larger and break up the rock even more. When the mosses die, they decay and add material and nutrients to the growing pile of soil. Thus, fertile soil forms from the broken rock, decayed organisms, water, and air. Primary succession can also be seen in any city street as shown in **Figure 20.** Mosses, lichens, and weeds can establish themselves in cracks in a sidewalk or building. Fungi and mosses can also invade a roof that needs repair. Even New York City would eventually turn into a cement-filled woodland if it were not constantly cleaned and maintained.

internet connect

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Topic: Ecological Succession
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Figure 20 ▶ Lichens (left) are colonizing a boulder in Wyoming. Over a long period of time, lichens can break down rock into soil. Plants that grow through cracks in city sidewalks (below) can also be described as pioneers of primary succession.

SECTION 3 Review

1. **Compare** primary and secondary succession.
2. **Describe** what role a pioneer species plays during the process of ecological succession.
3. **Explain** why putting out forest fires may be damaging in the long run.
4. **Describe** the role lichens play in primary succession. Write a short paragraph to explain your answer. WRITING SKILLS

CRITICAL THINKING

5. **Analyzing Processes** Over a period of 1,000 years, a lake becomes a maple forest. Is this process primary or secondary succession? Explain your answer.
6. **Analyzing Relationships** How are lichens similar to the pioneer species that colonize abandoned farm areas? How are they different?

CHAPTER 5 Highlights

1 Energy Flow in Ecosystems

Key Terms

photosynthesis, 117
producer, 118
consumer, 118
decomposer, 119
cellular respiration, 120
food chain, 122
food web, 122
trophic level, 122

Main Ideas

- The majority of the Earth's organisms depend on the sun for energy. Producers harness the sun's energy directly through photosynthesis, while consumers use the sun's energy indirectly by eating producers or other consumers.
- The paths of energy transfer can be followed through food chains, food webs, and trophic levels.
- Only about 10 percent of the energy that an organism consumes is stored and transferred when that organism is eaten.

2 The Cycling of Materials

Key Terms

carbon cycle, 124
nitrogen-fixing bacteria, 126
nitrogen cycle, 126
phosphorus cycle, 127

Main Ideas

- Materials in ecosystems are recycled and reused by natural processes.
- Carbon, nitrogen, and phosphorus are essential for life, and each of them follows a recognizable cycle.
- Humans can affect the cycling of materials in an ecosystem through activities such as burning fossil fuels and applying fertilizer to soil.

3 How Ecosystems Change

Key Terms

ecological succession, 129
primary succession, 129
secondary succession, 129
pioneer species, 130
climax community, 130

Main Ideas

- Organisms in an environment sometimes follow a pattern of change over time known as ecological succession.
- Secondary succession occurs on a surface where an ecosystem has previously existed. Primary succession occurs on a surface where no ecosystem existed before.
- Climax communities are made up of organisms that take over an ecosystem and remain until the ecosystem is disturbed again.

CHAPTER 5 Review

Using Key Terms

Use each of the following terms in a separate sentence.

1. *photosynthesis*
2. *trophic level*
3. *carbon cycle*
4. *nitrogen-fixing bacteria*
5. *decomposers*

For each pair of terms, explain how the meanings of the terms differ.

6. *producer* and *consumer*
7. *primary succession* and *secondary succession*
8. *nitrogen cycle* and *phosphorus cycle*
9. *food chain* and *food web*

STUDY TIP

Taking Multiple-Choice Tests When you take multiple-choice tests, be sure to read all of the choices before you pick the correct answer. Be patient, and eliminate choices that are obviously incorrect.

Understanding Key Ideas

10. Which of the following statements is *not* true of consumers?
    a. They get energy indirectly from the sun.
    b. They are also called *heterotrophs.*
    c. They make their own food.
    d. They sometimes eat other consumers.
11. Which of the following is correctly arranged from the lowest trophic level to the highest trophic level?
    a. bacteria, frog, eagle, mushroom
    b. algae, deer, wolf, hawk
    c. grass, mouse, snake, eagle
    d. grass, bass, minnow, snake
12. Communities of bacteria have been found living thousands of feet underwater. Which of the following statements is a proper conclusion to draw about these bacteria?
    a. Somehow they are conducting photosynthesis.
    b. They are living on borrowed time.
    c. They were somehow introduced by human activities.
    d. They use an energy source other than sunlight.
13. Which of the following pairs of organisms probably belong to the same trophic level?
    a. humans and bears
    b. bears and deer
    c. humans and cows
    d. both (a) and (c)
14. The energy lost between trophic levels
    a. can be captured only by parasitic organisms.
    b. cools the surrounding environment.
    c. is used in the course of normal living.
    d. evaporates in the atmosphere.
15. From producer to secondary consumer, about what percentage of energy is lost?
    a. 10 percent
    b. 90 percent
    c. 99 percent
    d. 100 percent
16. Which of the following statements about the nitrogen cycle is *not* true?
    a. Animals get nitrogen by eating plants or other animals.
    b. Plants generate nitrogen in their roots.
    c. Nitrogen moves back and forth between the atmosphere and living things.
    d. Decomposers break down waste to yield ammonia.
17. Which of the following are most likely to be the pioneer organisms on an area of bare rock?
    a. saplings
    b. shrubs
    c. lichens
    d. perennial grasses
18. Excessive use of fertilizer that contains nitrogen and phosphorus
    a. affects the carbon cycle.
    b. may cause algal blooms in waterways.
    c. causes soil erosion.
    d. contributes to primary succession.

CHAPTER 5 Review

Short Answer

19. Explain the relationship between cellular respiration and photosynthesis.

20. Why is the number of trophic levels that can exist limited?

21. Why are decomposers an essential part of an ecosystem?

22. Write a short paragraph that explains why the phosphorus cycle occurs slower than the carbon and nitrogen cycles. WRITING SKILLS

23. Describe the role of carbon dioxide in the carbon cycle.

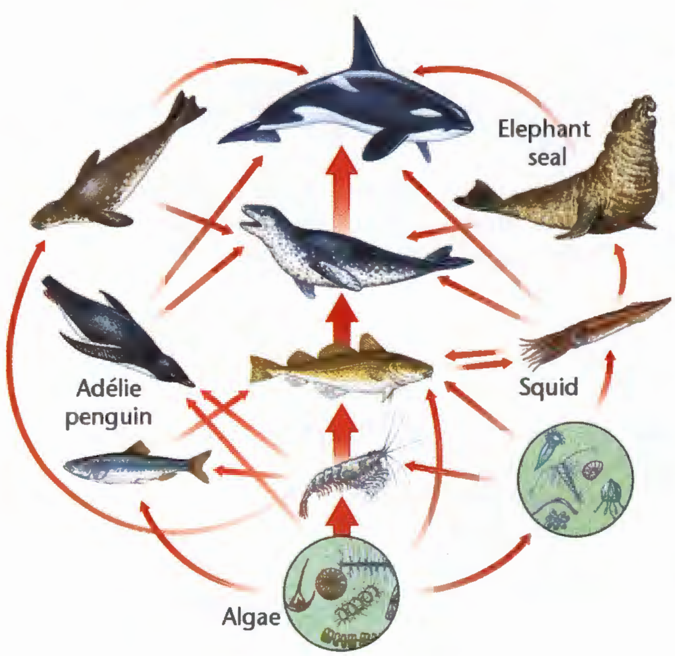
Interpreting Graphics

Use the diagram to answer questions 24–26.

24. How many organisms depend on the squid as a source of food?

25. If the population of Adélie penguins decreased drastically in this ecosystem, what effect would the decreased number of penguins have on elephant seals?

26. What role do algae play in this food web?



Concept Mapping

27. Use the following terms to create a concept map: *algae, humans, solar energy, carnivores, consumers, producers, directly, herbivores, indirectly,* and *omnivores.*

Critical Thinking

28. Comparing Processes How are producers and decomposers opposites of each other?

29. Inferring Relationships Abandoned fields in the southwestern part of the United States are often taken over by mesquite trees, which can grow in nutrient-poor soil. If the land is later cleared of mesquite, the soil is often found to be enriched with nitrogen and is more suitable for crops. What might be the reason for this phenomenon?

30. Understanding Concepts Read the description under the head, "What Eats What" in this chapter, and explain why decomposers are considered to be consumers. READING SKILLS

31. Drawing Conclusions Suppose that a plague eliminates all the primary consumers in an ecosystem. What will most likely happen to organisms in other trophic levels in this ecosystem?

Cross-Disciplinary Connection

32. Mathematics If a lake contains 600,000 kg of plankton and the top consumers are a population of 40 pike, which each weigh an average of 15 kg, how many trophic levels does the lake contain? Make a graph or pyramid that illustrates the trophic levels.

Portfolio Project

33. Research Local Succession Do a special project on succession. Find areas in your community that have been cleared of vegetation and left unattended at different times in the past. Ideally, you should find several areas that were cleared at different times, including recently and decades ago. Photograph each area, and arrange the pictures to show how succession takes place in your geographic region.

MATH SKILLS

Use the data in the table below to answer questions 34–35.

Percentage of Fertilizer Use per Year	
Region of the World	**Percentage**
North America	17
Asia	52
Africa	3
Europe	18
Latin America and the Caribbean	8
Oceania	2

34. **Making Calculations** If 137.25 million metric tons of fertilizer is used worldwide per year, how many million metric tons does Asia use?
35. **Graphing Data** Make a bar graph that compares the percentage of fertilizer use in different regions worldwide per year.

WRITING SKILLS

36. **Communicating Main Ideas** Describe the importance of the carbon, nitrogen, and phosphorus cycles to humans.
37. **Writing from Research** Research information on how countries regulate carbon dioxide emissions. Write an essay that describes the laws regulating carbon dioxide emissions and the solutions some countries have devised to decrease the amount of carbon dioxide emitted.

STANDARDIZED TEST PREP

For extra practice with questions formatted to represent the standardized test you may be asked to take at the end of your school year, turn to the sample test for this chapter in the Appendix.

READING SKILLS

Read the passage below, and then answer the questions that follow.

The Peruvian economy and many sea birds depend on normal atmospheric conditions. But sometimes, usually in December, the normal east-to-west winds do not form over the Pacific Ocean. Instead, winds push warm water eastward toward the coast of South America. When these conditions occur, the warm surface water cuts off the upwelling of nutrients. This event is called El Niño, which means "the child," because it happens near Christmas.

Because all convection cells are linked in the atmosphere, the effects of El Niño extend beyond Peru. Under a strong El Niño, northeastern Australia can suffer summer drought, which leads to reduced grain production there. The southeastern United States gets higher rainfall in El Niño years, which boosts agriculture and decreases forest fires.

1. According to the passage, a possible cause of reduced grain production in Australia is
   - **a.** a rate of convection that is higher than the average rate.
   - **b.** an amount of rainfall that is higher than the average amount.
   - **c.** a reduced fish population.
   - **d.** a summer drought.
2. According to the passage, which of the following statements is true?
   - **a.** The effects of El Niño do not extend beyond Peru.
   - **b.** During El Niño years, the U.S. agricultural industry suffers.
   - **c.** El Niño is caused by winds that push warm water eastward toward South America.
   - **d.** Australia's agricultural industry benefits the most from strong winds during El Niño.

CHAPTER 5

Exploration Lab: OBSERVATION

Objectives

- **Examine** the remains of an owl's diet.
- USING SCIENTIFIC METHODS **Construct** a food chain based on your observations.

Materials

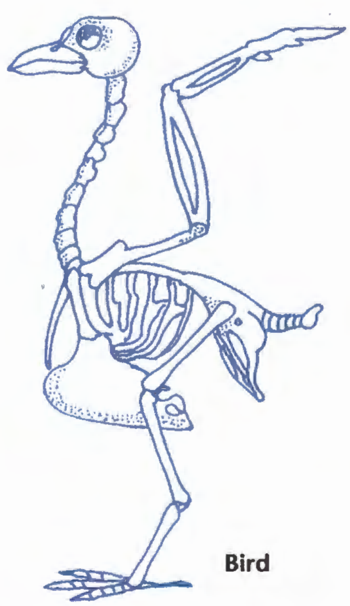
disposable gloves
dissecting needle
dissecting pan
egg cartons
forceps
owl pellet(s)
piece of white paper
small animal identification field guide that includes skull illustrations

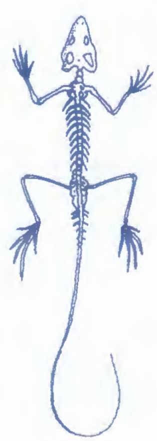
Dissecting Owl Pellets

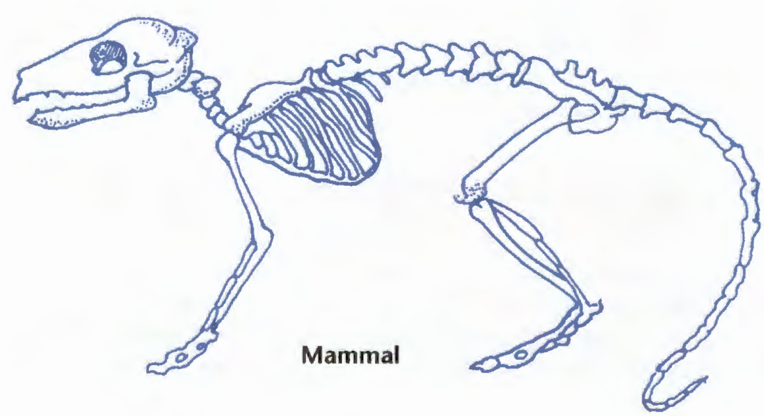
Owls are not known as finicky eaters. They prey on almost any animal that they can swallow whole. Like many other birds, owls have an interesting adaptation—a special structure called a gizzard. The gizzard acts as a filter and prevents the indigestible parts of their prey, such as fur, feathers, and bones—from passing into their intestines. These indigestible parts are passed to a storage pouch, where they accumulate. A few hours after consuming a meal, the owl coughs up the accumulated indigestible material, which has been compressed into a pellet. By examining such a pellet, you can tell what the owl ate. In addition, by examining the remains of the owl's prey found in the pellet, you can get a good idea of what the prey ate. Using this information, you can construct a food chain of the owl and its prey.

Procedure

1. Work in groups of three or four. Place an owl pellet in the dissecting pan, and remove it from its aluminum-foil casing.
2. Examine the owl pellet. Using the dissecting needle and forceps, carefully break apart the owl pellet. Separate the fur or feathers from the bones. Be careful not to damage the small bones. Place the bones onto a piece of white paper.
3. Identify the major components of the pellet.
4. If the pellet contains remains from more than one organism, determine as best as you can how many different animals and species are present.
5. Attempt to group the remains by type of organism. Count the number of skulls to find out how many prey were in the pellet. Decide which bones belong with which skulls. Then try to assemble complete skeletons. Sample skeletal diagrams are shown below.







▶ **Types of Organisms** Use these drawings to help you determine if the organism you put together is a bird, mammal, or reptile.

6. Closely examine the skulls of each prey. Compare the skulls to the diagrams of skulls on this page. What purpose do the teeth or bills seem to have—tearing flesh, chewing plant parts, or grinding seeds? If you are able to identify the prey, find out their typical food sources.
7. On a separate piece of paper, construct a simple food chain based on your findings.
8. Compare your findings with those of other groups of students.

Analysis

1. **Examining Data** How many skeletons were you able to make from your pellet? What kinds of animals did you identify in the owl pellet?
2. **Organizing Data** Compare your findings with those of your classmates by using the following questions:
   a. What animals were represented most often in the pellets?
   b. What common traits do these animals have?
   c. How many animals found in the pellets were herbivores? How many were carnivores?

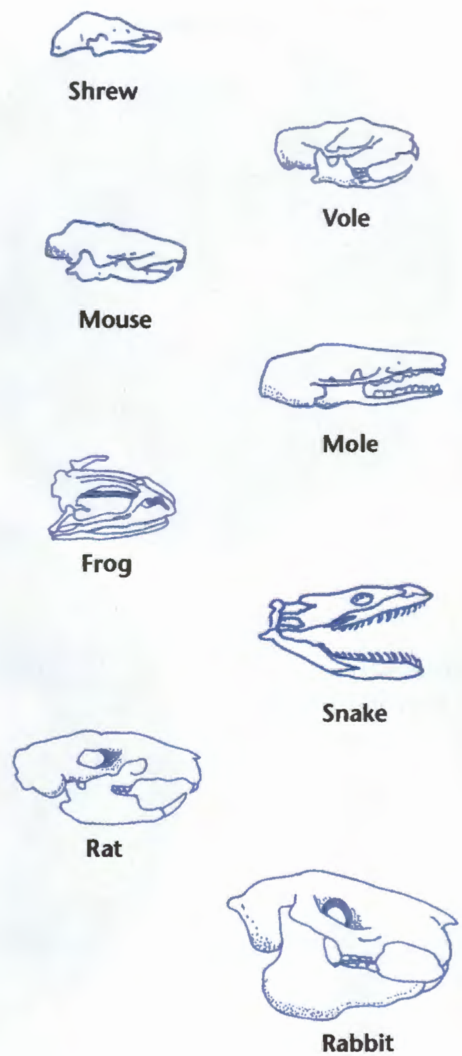
Conclusions

3. **Interpreting Information** What biological relationships were you able to determine from your examination of the owl pellets?
4. **Evaluating Data** Of the animals you found in your pellet, how many different trophic levels are represented?
5. **Drawing Conclusions** Most owls hunt at night and sleep during the day. From that information, what can you infer about their prey?

Extension

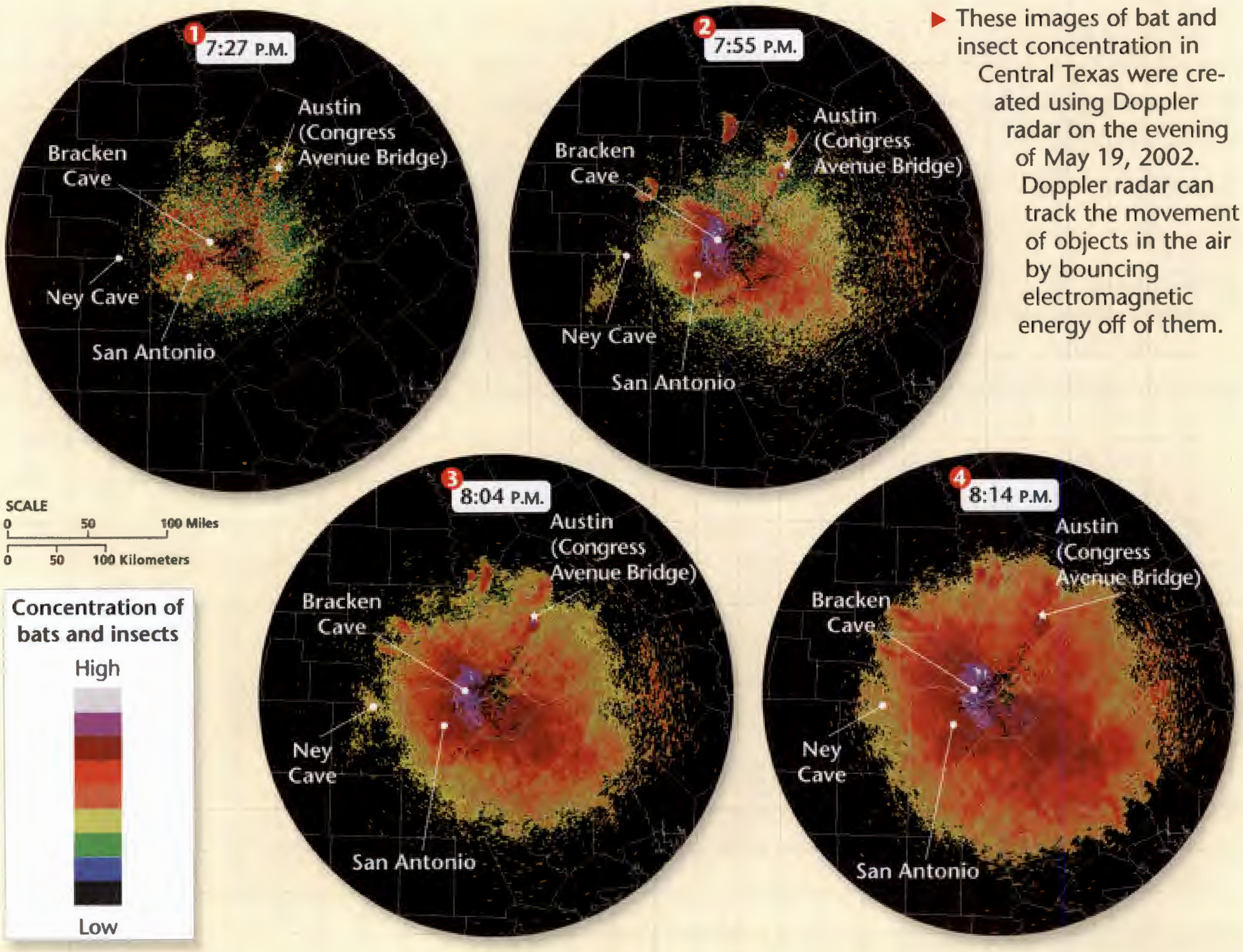
1. **Research and Communications** Research information on an owl species and the types of organisms found in its habitat. Make a poster of a food web, including the owl species. Be sure to include producers, consumers, and decomposers.

▶ **Identify the Prey** Use these drawings to identify the owl's prey.



MAPS in action

DOPPLER RADAR TRACKING OF BATS AND INSECTS IN CENTRAL TEXAS



▶ These images of bat and insect concentration in Central Texas were created using Doppler radar on the evening of May 19, 2002. Doppler radar can track the movement of objects in the air by bouncing electromagnetic energy off of them.

MAP SKILLS

Use the Doppler radar images of bats and insects in Central Texas to answer the questions below.

1. **Analyzing Data** At what time was the bat and insect concentration the lowest? At what time was the bat and insect concentration the highest?

2. **Using a Key** Use the concentration key to determine which area of Central Texas has the highest concentration of bats and insects at 8:14 P.M.

3. **Analyzing Data** Approximately how many kilometers wide is the concentration of bats and insects at 7:27 P.M.? at 8:14 P.M.?

4. **Inferring Relationships** Bracken Cave is home to 20 million bats that eat millions of pounds of insects nightly. Approximately how far is Bracken Cave from the city of San Antonio? If the bat population in the cave drastically decreased, what effect would this decrease have on the people living in San Antonio and Central Texas?

5. **Identifying Trends** These Doppler radar images of bats and insects were taken in the beginning of the summer season. How might these four images look in the month of December?

SOCIETY & the Environment

EATING THE BAIT

Most of the food we eat comes from agriculture and farming, but we also rely heavily on the fishing industry to provide us with fresh fish. Because of a high demand for fish, however, many fish species have become overharvested. Many organisms depend on these *fisheries,* places where fish are caught, to survive. The swordfish and cod fisheries of the North Atlantic and the salmon fishery off the northwestern coast of the United States are examples of fisheries that have become depleted. These fisheries now contain so few fish that harvesting these fish is not economical.

▶ **Overfishing** of organisms from higher trophic levels has forced the commercial fishing industry to harvest organisms in lower trophic levels in order to fulfill the demand for fresh fish.

Fishing Down the Food Chain

Fish such as cod, tuna, and snapper are top carnivores in ocean food chains and food webs. As these fish have disappeared, species from lower trophic levels have begun to appear in fish markets. Fish that were once swept back into the sea when they were caught in nets by accident are now being kept and sold. Organisms from lower trophic levels such as mullet, squid, mackerel, and herring, which were typically used as bait to catch larger fish, now appear on restaurant menus.

According to data from the United Nations on worldwide fish harvests, the overall trophic level at which most fish are caught has declined since the 1950s. Overfishing of organisms in lower trophic levels disrupts food chains and food webs. If the food webs of ocean ecosystems collapse, the commercial fishing industry will also collapse. For example, in the North Atlantic cod fisheries, the cod began to disappear, so the fishermen concentrated on the cods' prey, which is shrimp. Cod are higher trophic level organisms, while shrimp are in the lower trophic levels and feed on algae and detritus. If the shrimp and the cod become overfished, the other organisms that depend on both the shrimp and cod to survive are affected.

Creating Sustainable Fisheries

One aim of environmental science is to determine how fisheries can be managed so that they are sustainable or capable of supplying the same number of fish to be harvested each year. However, few, if any, countries manage their fisheries in this way. Almost all countries permit unsustainable, large harvests. One solution to overfishing is to establish "no-take" zones. These are areas of the sea where no fishing is permitted. Studies have shown that fish populations grow rapidly in "no-take" zones. When a population grows in a "no-take zone," the higher trophic level organisms leave the zone and become available to fishermen. "No-take" zones help populations recover and allow food chains and food webs to remain intact.

▶ A squid is an example of an organism from a lower trophic level that was used for bait but is now sold in restaurants.

What Do You Think?

The next time you go to a fish market or seafood restaurant, take note of the different types of species for sale. Write down the names of the species, and try to assign each species to a trophic level. How many of the species for sale belong to lower trophic levels? How many belong to higher trophic levels? How do prices differ between the species for sale?