CHAPTER 18

INTRODUCTION TO ECOLOGY

Ecology is the study of the interactions of organisms with each other and with the nonliving parts of Earth. This image is a view of Earth as seen from space.

BIOLOGY INTERACTIVE TUTOR

Unit 7—Ecosystem Dynamics
Topics 1, 4–6

Introduction to Ecology

__Ecology__ is the study of the interactions between organisms and the living and nonliving components of their environment. Each of the variety of organisms on Earth depends in some way on other living and nonliving things in its environment. Ecology is a broad science that involves collecting information about organisms and their environments, observing and measuring interactions, looking for patterns, and seeking to explain these patterns.

SECTION 1

OBJECTIVES

- **Identify** a key theme in ecology.
- **Describe** an example showing the effects of interdependence upon organisms in their environment.
- **Identify** the importance of models to ecology.
- **State** the five different levels of organization at which ecology can be studied.

VOCABULARY

ecology
interdependence
ecological model
biosphere
ecosystem
community
population

INTERDEPENDENCE: A KEY THEME IN ECOLOGY

Although the field of ecology was not named until 1866, ecological information and understanding have always been crucial to humans. Before the development of agriculture, about 10,000–12,000 years ago, our ancestors obtained all of their food by hunting animals and gathering plants, seeds, berries, and nuts. Their survival depended on practical knowledge about the environment. Although most humans today don't survive as hunter-gatherers, they interact with the environment and other organisms every day.

Organisms and Their Environments

All organisms interact with other organisms in their surroundings and with the nonliving portion of their environment. Their survival depends on these interactions. Ecologists refer to this quality as *interconnectedness* or **interdependence.**

Interdependence is a key theme found throughout ecology. For example, you could not survive without the plants and other photosynthetic organisms that produce oxygen. Your cells need oxygen to release the energy in food, and cells will die if deprived of oxygen for even a few minutes. Conversely, photosynthetic organisms depend on the release of carbon dioxide gas by the cellular respiration of other organisms, such as humans, and geochemical processes, such as volcanic eruptions. Carbon dioxide gas is an essential raw material for making carbohydrates by photosynthesizers.

Word Roots and Origins

ecology

from the Greek *oikos,* meaning "house," and *logos,* meaning "study of"

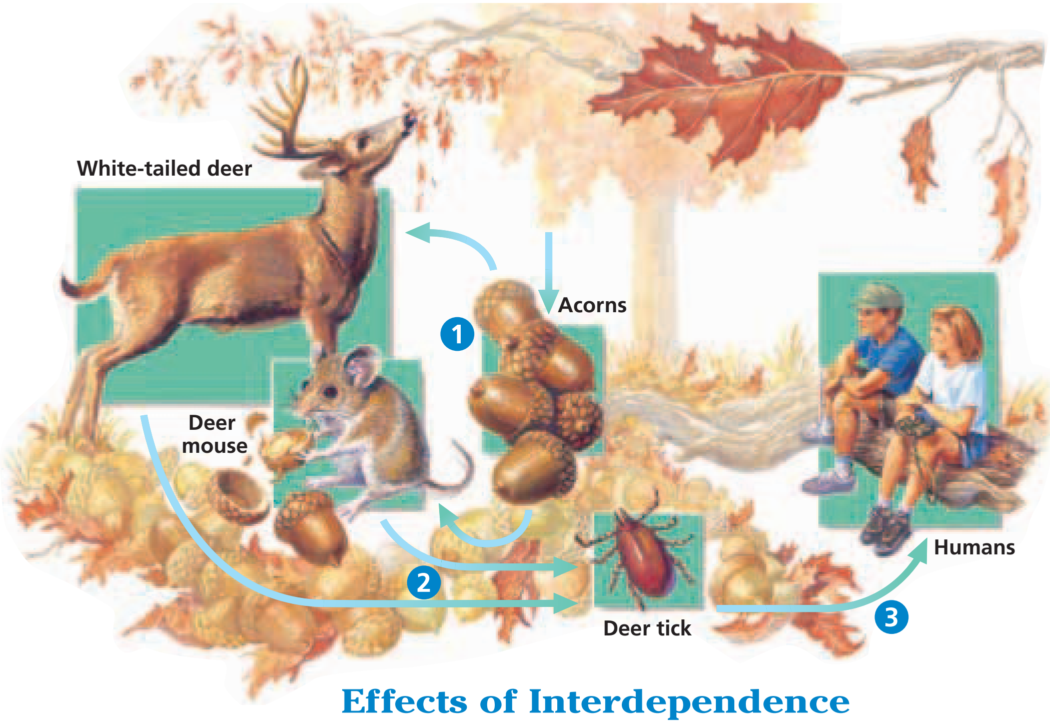

FIGURE 18-1

All of the different species shown are interconnected in the forest. 1 An unusually plentiful crop of acorns helps support a large population of deer and mice. 2 The deer and mice help support a large population of ticks. 3 Ticks carry the bacterium that causes Lyme disease. They pass on the disease to humans who visit the forest.

Effects of Interdependence

A consequence of interdependence is that any change in the environment can spread through the network of interactions and affect organisms that appear far removed from the change. One example is the interrelationships among species in forests in the eastern United States. Through these relationships, as shown in Figure 18-1, acorn production is connected to the spread of Lyme disease, an infection that can damage the human nervous system.

In most years, oak trees produce few or no acorns. Every few years, however, they produce a huge crop of acorns. The large number of acorns supports larger populations of deer and mice, which feed on acorns. Ticks feed on the blood of animals, so the tick population also increases. The increased number of ticks increases the chance that ticks will bite any humans in the forest. The bite of the deer tick can transmit the bacterium that causes Lyme disease to humans. So, in general, after a season of high acorn production, the cases of Lyme disease increase.

ECOLOGICAL MODELS

Ecology is extremely complex and difficult to study. One way that ecologists deal with this complexity is to use **ecological models** to represent or describe the components of an ecological system. A model may be physical, conceptual, or mathematical. Ecologists construct models to help them understand environmental interactions and to make predictions about possible changes. These predictions can be tested by comparing them with observations from the natural world. Models are widely used to help plan and evaluate solutions to environmental problems. However, an ecological model may be limited in its application, because it cannot always account for the influence of every variable in a real environment.

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LEVELS OF ORGANIZATION

Scientists recognize a hierarchy of different levels of organization within organisms. Each organism is composed of one or more organs. Each organ is composed of tissues, which, in turn, are composed of cells, and so on. Likewise, ecologists recognize a hierarchy of organization in the environment, as illustrated in Figure 18-2.

Each level has unique properties that result from interactions between its components, so a complete study of ecology would look at all levels. But for practical reasons, ecologists often focus their research on one level of organization while recognizing that each level is influenced by processes at other levels.

The Biosphere

The broadest, most inclusive level of organization is the **biosphere** (BIE-oh-SFIR), the thin volume of Earth and its atmosphere that supports life. All organisms are found within the biosphere. It is about 20 km (13 mi) thick and extends from about 8 to 10 km (5 to 6 mi) above the Earth's surface to the deepest parts of the oceans. In comparison, the Earth's diameter is about 12,700 km (7,900 mi), or more than 600 times the thickness of the biosphere. If Earth were the size of an apple, the biosphere would only be as thick as the apple's skin. Ecologists often describe the biosphere as a thin film of life covering an otherwise lifeless planet. Living things are not distributed evenly throughout the biosphere. Many organisms are found within a few meters of the surface of the land or oceans.

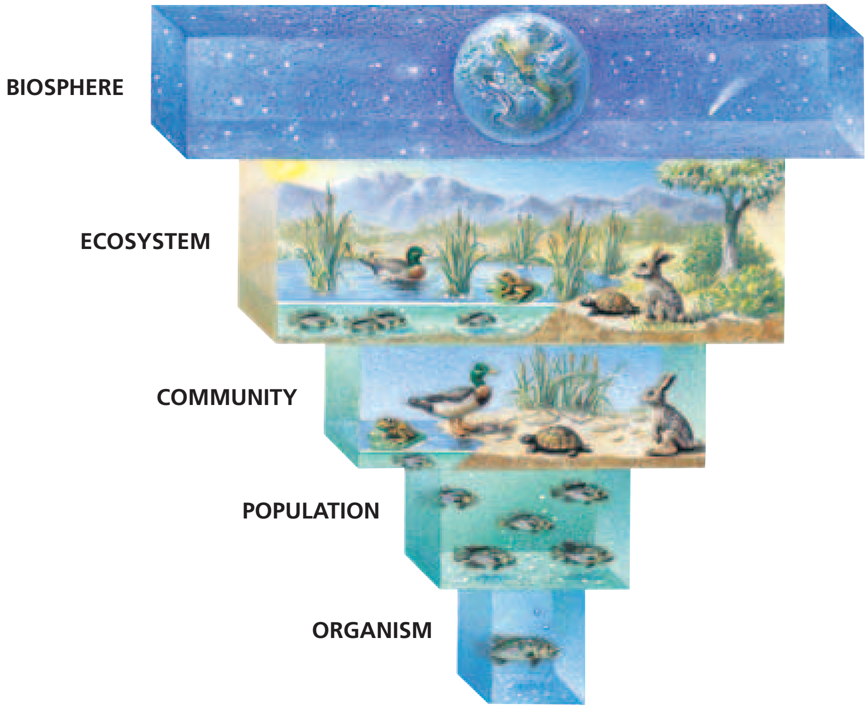


FIGURE 18-2

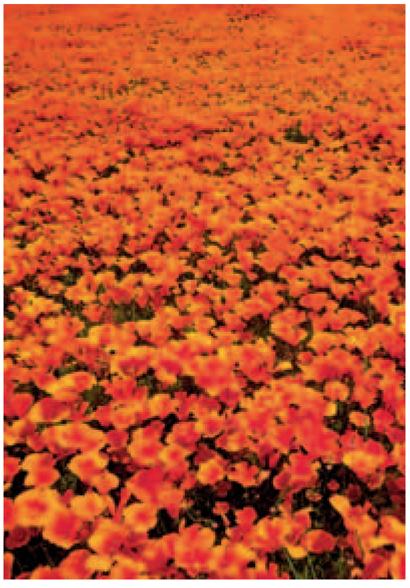
Ecology has been organized into five levels because of the complexity of the science. This diagram is a model illustrating the hierarchical organization of ecology.

Ecosystems

The biosphere is composed of smaller units called ecosystems. An **ecosystem** (EK-oh-SIS-tuhm) includes all of the organisms and the nonliving environment found in a particular place. Consider a pond ecosystem. It contains a variety of living things, such as fish, turtles, aquatic plants, algae, insects, and bacteria. These organisms interact in ways that affect their survival. For instance, insects and fish eat aquatic plants, and turtles eat fish. The pond ecosystem also includes all the nonliving (physical and chemical) aspects of the pond that influence its inhabitants. The chemical composition of the pond—its pH, its levels of dissolved oxygen and carbon dioxide, and its supply of nitrogen—helps to determine what kinds of organisms live in the pond and how abundant they are. A very important physical factor is the amount of sunlight the pond receives, because sunlight is the ultimate source of energy for the pond's inhabitants.

FIGURE 18-3

These flowers represent a population of California poppies, *Eschscholzia californica,* living in California.



Communities, Populations, and Organisms

Whereas an ecosystem contains both living and nonliving components, a community includes only species of organisms. A **community** is all the interacting organisms living in an area. For instance, all the fish, turtles, plants, algae, and bacteria in the pond described above make up a community. Although it is less inclusive than an ecosystem, a community is still very complex, and it may contain thousands of species. Ecologists studying a community often focus on how species interact and how these interactions influence the nature of the community. Remember that the word *community* has a specific meaning in biology that differs from its everyday meaning.

Below the community level of organization is the population level, where the focus is on the members of a single species. A **population** includes all the members of a species that live in one place at one time. An example of a population of flowers is shown in Figure 18-3. The simplest level of organization in ecology is that of the organism. Research at this level concentrates on the adaptations that allow organisms to overcome the challenges of their environment.

SECTION 1 REVIEW

1. Explain why interdependence is an important theme in ecology.
2. Describe one example of the effects of interdependence upon organisms in their environment.
3. Why are models used so often in the science of ecology?
4. How does a population differ from a community?
5. Define the term *biosphere*.
6. List the five main levels of organization in ecology.

CRITICAL THINKING

7. **Predicting Results** Assuming wolves eat deer, how could a disease that kills a large portion of the wolf population affect the mice population in a forest ecosystem?
8. **Analyzing Concepts** Why is the amount of sunlight important to the animals in an ecosystem?
9. **Applying Information** Would bacteria that inhabit a cave deep inside Earth be considered part of the biosphere? Explain.

ECOLOGY OF ORGANISMS

*The place where an organism lives is its **habitat.** But why does it live there and not elsewhere? What parts of its habitat does it use? The answers to these questions depend on an organism's evolutionary history, its abilities, and its needs.*

SECTION 2

OBJECTIVES

- **Compare** abiotic factors with biotic factors, and list two examples of each.
- **Describe** two mechanisms that allow organisms to survive in a changing environment.
- **Explain** the concept of the niche.

VOCABULARY

habitat
biotic factor
abiotic factor
tolerance curve
acclimation
conformer
regulator
dormancy
migration
niche
generalist
specialist

ECOSYSTEM COMPONENTS

Ecologists separate the environmental factors that influence an organism into two types. The living components of the environment are called **biotic** (bie-AHT-ik) **factors.** Biotic factors include all of the living things that affect the organism. The nonliving factors, called **abiotic** (AY-bie-AHT-ik) **factors,** are the physical and chemical characteristics of the environment.

Biotic and Abiotic Factors

Abiotic factors include temperature, humidity, pH, salinity, oxygen concentration, amount of sunlight, availability of nitrogen, and precipitation. The importance of each factor varies from environment to environment. Abiotic and biotic factors are not independent; organisms change their environment and are influenced by those changes. For example, the availability of nitrogen in the soil affects how fast plants can grow, and plants affect nitrogen availability by absorbing nitrogen from the soil.

Abiotic factors are not constant. They vary from place to place and over time, as shown in Figure 18-4. Consider temperature, which is a very important abiotic factor. Temperature varies from hour to hour, from day to day, from season to season, and from place to place. Also important are the small differences in temperature within a habitat, such as the difference between an area in the shade of a tree and an area exposed to direct sunlight.

FIGURE 18-4

These pictures show the same area of forest at different times of the year. On the top, the forest displays spring foliage. On the bottom, the same area is covered with snow in the winter.

ORGANISMS IN A CHANGING ENVIRONMENT

Each organism is able to survive within a limited range of environmental conditions. For example, an organism may be able to function only within a specific range of temperatures. It is possible to determine this range for an organism by measuring how efficiently it performs at different temperatures. A graph of performance versus values of an environmental variable, such as temperature, is called a **tolerance curve.**

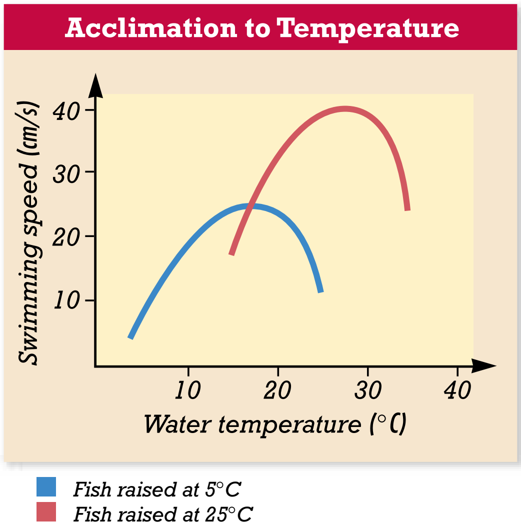


FIGURE 18-5

Goldfish raised at 25°C are acclimated to higher temperatures, so they have a different tolerance curve than the fish raised at 5°C do.

An organism can survive and function in conditions outside its optimal range, but its performance is greatly reduced. It cannot survive under conditions that fall outside its tolerance limits. An organism's range may be determined by the levels of one or more factors, such as pH, temperature, or salinity.

Acclimation

Some organisms can adjust their tolerance to abiotic factors through the process of **acclimation** (AK-luh-MAY-shuhn). For example, goldfish raised at different temperatures have somewhat different tolerance curves, as shown in Figure 18-5. Be sure not to confuse *acclimation* with *adaptation*. Acclimation occurs within the lifetime of an individual organism. Adaptation is genetic change in a species or population that occurs from generation to generation over time.

Control of Internal Conditions

Environments fluctuate in temperature, light, moisture, salinity, and other chemical factors. There are two ways for organisms to deal with some of these changes in their environment. **Conformers** are organisms that do not regulate their internal conditions; they change as their external environment changes. The internal conditions of a conformer remain within the optimal range only as long as environmental conditions remain within that range. In contrast, **regulators** are organisms that use energy to control some of their internal conditions. Regulators can keep an internal condition within the optimal range over a wide variety of environmental conditions.

Careers in BIOLOGY

Canopy Scientist

Job Description Canopy scientists are biologists who study the forest canopy—the uppermost layer of trees. Today's researchers use a variety of equipment to reach the canopy. Canopy scientists can work in universities, botanical gardens, museums, and government and conservation agencies.

Focus On a Canopy Scientist

"I'm on the edge of discovering what is new. Plus, I get to climb trees!" Nalini Nadkarni teaches at a university and conducts research in both tropical and temperate forests. She has also invited artists and musicians to visit the canopy. "I try to understand the science of the canopy, but artists and musicians help capture its aesthetic value." Nadkarni knows that her job is important. The forests she studies are important factors in world climate and are home to many unique species.

Education and Skills

- **High School**—three years of science courses and four years of math courses.
- **College**—bachelor of science in biology, including course work in botany, zoology, ecology, geography, and data analysis; a master's (M.S.) or doctoral degree (Ph.D.) for research.
- **Skills**—self-motivation, curiosity, patience, good observation skills, research skills, computer literacy, quick thinking, and field survival skills.

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Escape from Unsuitable Conditions

Some species can survive unfavorable environmental conditions by escaping from them temporarily. For example, desert animals usually hide underground or in the shade during the hottest part of the day. Many desert species are active at night, when temperatures are much lower. A longer-term strategy is to enter a state of reduced activity, called **dormancy,** during periods of unfavorable conditions, such as winter or drought. Another strategy is to move to a more favorable habitat, called **migration.** An example of migration is the seasonal movements of birds, which spend spring and summer in cooler climates and migrate to warmer climates in the fall.

THE NICHE

Species do not use or occupy all parts of their habitat at once. The specific role, or way of life, of a species within its environment is its **niche** (NICH). The niche includes the range of conditions that the species can tolerate, the resources it uses, the methods by which it obtains resources, the number of offspring it has, its time of reproduction, and all other interactions with its environment. Parts of a lion's niche are shown in Figure 18-6.

Generalists are species with broad niches; they can tolerate a range of conditions and use a variety of resources. An example of a generalist is the Virginia opossum, found across much of the United States. The opossum feeds on almost anything, from eggs and dead animals to fruits and plants. In contrast, species that have narrow niches are called **specialists.** An example is the koala of Australia, which feeds only on the leaves of a few species of eucalyptus trees.

Some species have more than one niche within a lifetime. For example, caterpillars eat the leaves of plants, but as adult butterflies, they feed on nectar.

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Word Roots and Origins

niche

from the Old French *nichier,* meaning "to nest"

FIGURE 18-6
Plants and animals are able to share the same habitats because they each have different niches.

SECTION 2 REVIEW

1. Distinguish between biotic and abiotic factors.
2. Explain how migration allows organisms to cope with a changing environment.
3. What does a tolerance curve indicate about an organism?
4. How does an organism's niche differ from its habitat?
5. Give examples of a generalist and a specialist not mentioned in the text above.

CRITICAL THINKING

6. **Analyzing Concepts** Why do different species never occupy exactly the same niche?
7. **Applying Information** If some of the resources in a habitat are destroyed, which would be more likely to survive, a generalist species or a specialist species? Explain.
8. **Drawing Conclusions** A small rodent species and a bird species are adapted to cold temperatures. How might each species survive a major temperature increase?

SECTION 3

OBJECTIVES

- **Summarize** the role of producers in an ecosystem.
- **Identify** several kinds of consumers in an ecosystem.
- **Explain** the important role of decomposers in an ecosystem.
- **Compare** the concept of a food chain with that of a food web.
- **Explain** why ecosystems usually contain only a few trophic levels.

VOCABULARY

producer
chemosynthesis
gross primary productivity
biomass
net primary productivity
consumer
herbivore
carnivore
omnivore
detritivore
decomposer
trophic level
food chain
food web

ENERGY TRANSFER

All organisms need energy to carry out essential functions, such as growth, movement, maintenance and repair, and reproduction. In an ecosystem, energy flows from the sun to autotrophs, then to organisms that eat the autotrophs, and then to organisms that feed on other organisms. The amount of energy an ecosystem receives and the amount that is transferred from organism to organism affect the ecosystem's structure.

PRODUCERS

Autotrophs, which include plants and some kinds of protists and bacteria, manufacture their own food. Because autotrophs capture energy and use it to make organic molecules, they are called **producers.** Recall that *organic* molecules are molecules that contain carbon.

Most producers are photosynthetic, so they use solar energy to power the production of food. However, some autotrophic bacteria do not use sunlight as an energy source. These bacteria carry out **chemosynthesis** (KEE-moh-SIN-thuh-sis), in which they use energy stored in inorganic molecules to produce carbohydrates. In terrestrial ecosystems, plants are usually the major producers. In aquatic ecosystems, photosynthetic protists and bacteria are usually the major producers.

Measuring Productivity

Gross primary productivity is the rate at which producers in an ecosystem capture the energy of sunlight by producing organic compounds. Photosynthetic producers use energy and carbon dioxide to make sugar, an energy-rich organic molecule. Some of the sugar is used for cellular respiration, some is used for maintenance and repair, and some is used for making new organic material through either growth or reproduction. Ecologists refer to the organic material that has been produced in an ecosystem as **biomass.** Producers add biomass to an ecosystem by making organic molecules.

Only energy stored as biomass is available to other organisms in the ecosystem. Ecologists often measure the rate at which biomass accumulates, called the **net primary productivity.** Net primary productivity is typically expressed in units of energy per unit area per year (kcal/m^2/y) or in units of dry organic mass per unit area per year (g/m^2/y). Net primary productivity equals gross primary productivity minus the rate of respiration in producers.

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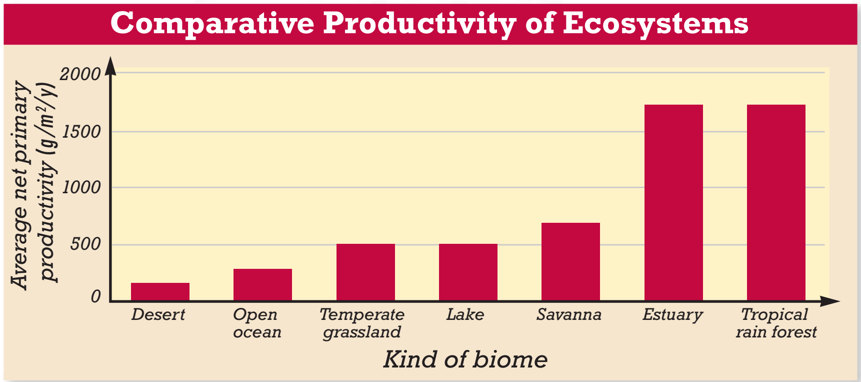


FIGURE 18-7

As the histogram shows, the net primary productivity in a tropical rain forest is very similar to the net primary productivity in an estuary. Temperate grasslands and freshwater lakes are also very similar in productivity.

Figure 18-7 shows that net primary productivity can vary greatly between ecosystems. For example, the average net primary productivity in a tropical rain forest is 25 times greater than the rate in a desert of the same size. Although rain forests occupy only about 5 percent of Earth's surface, they account for almost 30 percent of the world's net primary productivity. Variations in three factors—light, temperature, and precipitation—account for most of the variation in productivity among terrestrial ecosystems. An increase in any of these variables usually leads to a productivity increase. In aquatic ecosystems, productivity is usually determined by only two factors: light and the availability of nutrients.

Word Roots and Origins

omnivore

from the Latin *omnis,* meaning "all," and *-vore,* meaning "one who eats"

CONSUMERS

All animals, most protists, all fungi, and many bacteria are heterotrophs. Unlike autotrophs, heterotrophs cannot manufacture their own food. Instead, they get energy by eating other organisms or organic wastes. Ecologically speaking, heterotrophs are **consumers.** They obtain energy by consuming organic molecules made by other organisms. Consumers can be grouped according to the type of food they eat. **Herbivores** eat producers. An antelope that eats grass is a herbivore. **Carnivores** eat other consumers. Lions, cobras, and praying mantises are examples of carnivores. **Omnivores** eat both producers and consumers. The grizzly bear, whose diet ranges from berries to salmon, is an omnivore.

Detritivores (dee-TRIET-uh-VAWRZ) are consumers that feed on the "garbage" of an ecosystem. This waste, or *detritus,* includes organisms that have recently died, fallen leaves, and animal wastes. The vulture shown in Figure 18-8 is a detritivore. Many bacteria and fungi are detritivores that cause decay by breaking down complex molecules into simpler molecules. So, they are specifically called **decomposers.** Some of the molecules released during decay are absorbed by the decomposers, and some are returned to the soil or water. Decomposers make the nutrients that were contained in detritus available again to the autotrophs in the ecosystem. Thus, the process of decomposition recycles chemical nutrients.

FIGURE 18-8

This turkey vulture, *Cathartes aura,* is a detritivore that consumes dead animals. Detritivores play the important role of cleaning up dead organisms and aiding decomposition.

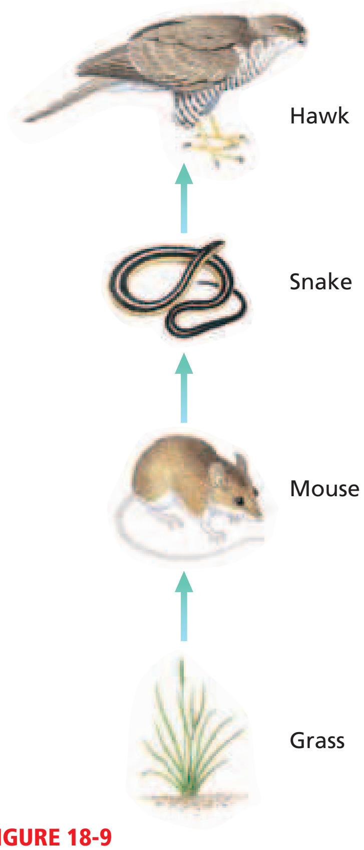


FIGURE 18-9

Energy is transferred from one organism to another in a food chain. The food chain shown above begins with a producer, grass, and ends with a carnivore, a hawk.

ENERGY FLOW

When one organism eats another, molecules are metabolized and energy is transferred. As a result, energy flows through an ecosystem, moving from producers to consumers. One way to follow the pattern of energy flow is to group organisms in an ecosystem based on how they obtain energy. An organism's **trophic** (TRAHF-ik) **level** indicates the organism's position in a sequence of energy transfers. For example, all producers belong to the first trophic level. Herbivores belong to the second trophic level, and the predators belong to the third level. Most terrestrial ecosystems have only three or four trophic levels, whereas marine ecosystems often have more.

Food Chains and Food Webs

A **food chain** is a single pathway of feeding relationships among organisms in an ecosystem that results in energy transfer. A food chain may begin with grass, which is a primary producer. The chain may continue with a consumer of grass seeds—a meadow mouse. Next, a carnivorous snake may kill and eat the mouse. A hawk then may eat the snake, as shown in Figure 18-9.

The feeding relationships in an ecosystem are usually too complex to be represented by a single food chain. Many consumers eat more than one type of food. In addition, more than one species of consumer may feed on the same organism. Many food chains interlink, and a diagram of the feeding relationships among all the organisms in an ecosystem would resemble a web, as shown in Figure 18-10. For this reason, the interrelated food chains in an ecosystem are called a **food web.**

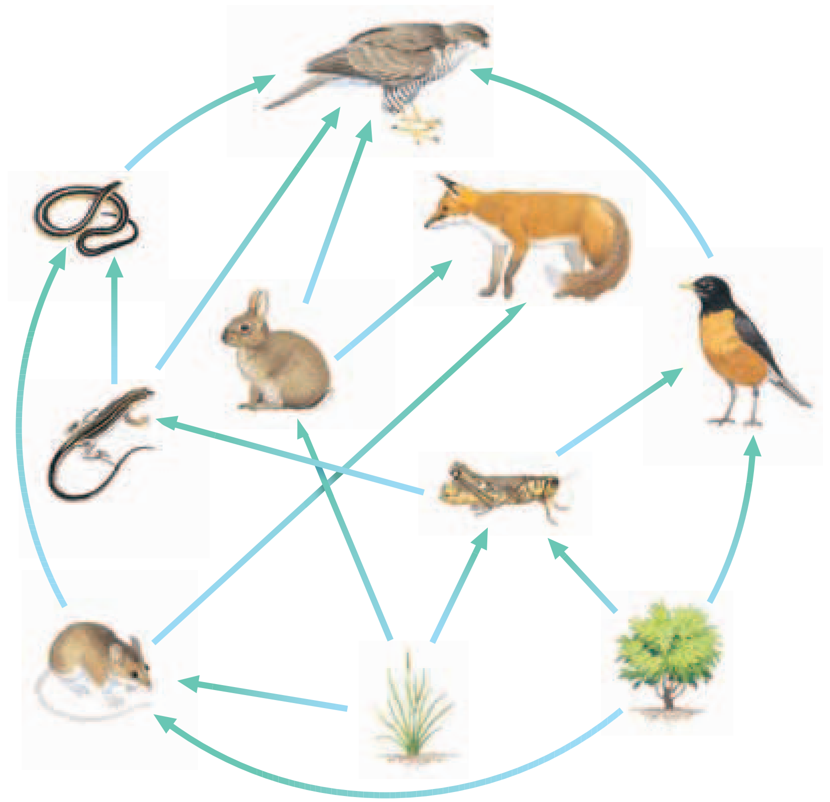


FIGURE 18-10

Because a large carnivore may be at the top of several food chains, it is helpful to show as many feeding relationships as possible in a food-web diagram. Not all organisms are listed in the food web. For example, no decomposers are shown.

Energy Transfer

Figure 18-11 represents the amount of energy stored as organic material in each trophic level in an ecosystem. The pyramid shape of the diagram indicates the low percentage of energy transfer from one level to the next. On average, 10 percent of the total energy consumed in one trophic level is incorporated into the organisms in the next.

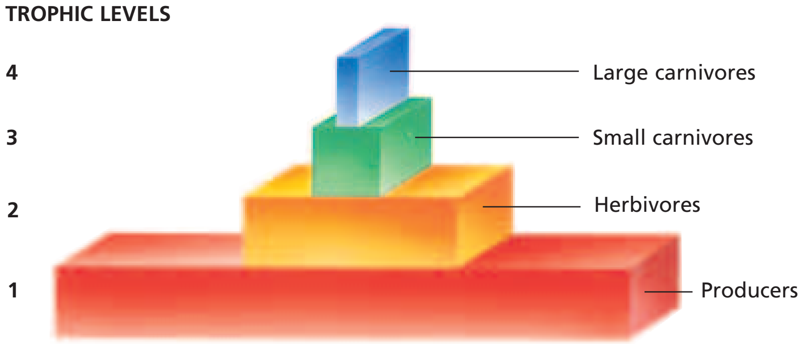


FIGURE 18-11
This diagram represents energy transfer through four trophic levels. The amount of energy transferred from one level to another can vary, so the structure shown can vary. What is always true, however, is that the top level is much smaller than the lowest level. Hence, energy-transfer diagrams are always roughly pyramid shaped.

Why is the percentage of energy transfer so low? One reason is that some of the organisms in a trophic level escape being eaten. They eventually die and become food for decomposers, but the energy contained in their bodies does not pass to a higher trophic level. Even when an organism is eaten, some of the molecules in its body will be in a form that the consumer cannot break down and use. For example, a cougar cannot extract energy from the antlers, hooves, and hair of a deer. Also, the energy used by prey for cellular respiration cannot be used by predators to synthesize new biomass. Finally, no transformation or transfer of energy is 100 percent efficient. Every time energy is transformed, such as during the reactions of metabolism, some energy is lost as heat.

Limitations of Trophic Levels

The low rate of energy transfer between trophic levels explains why ecosystems rarely contain more than a few trophic levels. Because only about 10 percent of the energy available at one trophic level is transferred to the next trophic level, there is not enough energy in the top trophic level to support more levels.

Organisms at the lowest trophic level are usually much more abundant than organisms at the highest level. In Africa, for example, you will see about 1,000 zebras, gazelles, and other herbivores for every lion or leopard you see, and there are far more grasses and shrubs than there are herbivores. Higher trophic levels contain less energy, so, they can support fewer individuals.

SECTION 3 REVIEW

1. How do producers and consumers obtain energy?
2. Name five types of consumers.
3. What important role do decomposers play in an ecosystem?
4. How does a food chain differ from a food web?
5. Give two reasons for the low rate of energy transfer within ecosystems.
6. Explain why food chains usually do not exceed three to four levels.

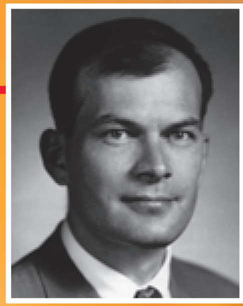
CRITICAL THINKING

7. **Predicting Results** Describe the probable effects on an ecosystem if all the plants were to die. What if all the decomposers were to die?
8. **Evaluating Models** A student has modeled a terrestrial ecosystem with seven trophic levels. Is this number reasonable? Explain.
9. **Analyzing Concepts** Explain why the same area can support a greater number of herbivores than carnivores.

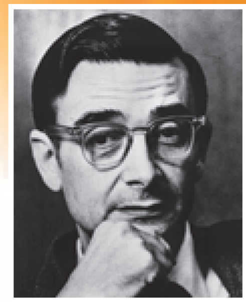
Science in Action

Testing a Theory of Biogeography

In the 1960s, mathematical ecologist Robert H. MacArthur of Princeton University and taxonomist Edward O. Wilson of Harvard University developed a theory and mathematical model of island biogeography based on their study of species on islands. This model, and others inspired by it, is used to explain patterns of species distribution around the world.



Robert H. MacArthur



Edward O. Wilson

HYPOTHESIS: The Number of Species on Any Island Is Constant

Ant biologist Edward O. Wilson (1929–) and mathematical ecologist Robert H. MacArthur (1930–1972) were both interested in community patterns within nature. Shortly after they met, they decided to work together on a study of species on islands.

Wilson noticed that the number of ant species on an island correlate with the size of the island. He also noticed that when a new ant species arrives on an island, one of the species already on the island becomes extinct. However, the total number of ant species remains constant. Wilson and MacArthur hypothesized that islands have a constant number of species. They proposed that the number of species on an island reflects an equilibrium—a balance between the rate at which new species colonize the island and the rate at which established species become extinct.

METHOD: Construct and Test a Model

MacArthur and Wilson developed a mathematical model to explain their observations. The mathematics of the theory is complex, but the broad outlines center on two observable patterns: (1) large islands have more species than small islands have and (2) remote islands—those located far from the mainland or from a larger island—have fewer species than less remote ones.

MacArthur and Wilson decided to test their model on Krakatau, an island in Indonesia on which a volcano had erupted in 1883, killing most forms of life on the island. The return of plant and animal life to the island had been carefully recorded since Krakatau was first revisited in 1886.

RESULTS: Species Reached Equilibrium

After examining the records of bird life at Krakatau, they learned that the number of species had climbed to 27 before leveling off.

CONCLUSION: Prediction Was Close

Using their model, MacArthur and Wilson predicted that at the point of equilibrium, the number of bird species would be about 30. Their prediction had come close.

Recent Tests of Island Biogeography

More recent studies of islands, such as those in the Sea of Cortez, suggest that many models of island biogeography may be required to explain patterns of species distributions. Researchers have generated alternative models that account for factors such as island history, climate, and species interactions.

When the volcano that forms the island of Krakatau erupted in the 1880s, it destroyed most life on the island. As life returned, scientists had a unique opportunity to study ecology in action.

REVIEW

1. Describe MacArthur and Wilson's model of island biogeography.
2. Summarize the results from testing the model on Krakatau.
3. **Critical Thinking** Suggest how island factors might prevent equilibrium from being reached in MacArthur and Wilson's model.

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Topic: Island Biogeography

Keyword: HM61693

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Ecosystem Recycling

As energy and matter flow through an ecosystem, matter must be recycled and reused. Substances such as water, carbon, nitrogen, calcium, and phosphorus each pass between the living and nonliving worlds through ***biogeochemical cycles.***

THE WATER CYCLE

Water is crucial to life. Cells contain 70 to 90 percent water, and water provides the environment in which most of life's chemical reactions occur. The availability of water is one of the key factors that regulate the productivity of terrestrial ecosystems. However, very little of the available water on Earth is trapped within living things at any given time. Bodies of water, such as lakes, rivers, streams, and oceans, contain a substantial percentage of Earth's water. The atmosphere also contains water—in the form of water vapor. In addition, some water is found below ground. Water in the soil or in underground formations of porous rock is known as **groundwater.**

The movement of water between these various reservoirs, known as the **water cycle,** is illustrated in Figure 18-12. Three important processes in the water cycle are evaporation, transpiration, and precipitation.

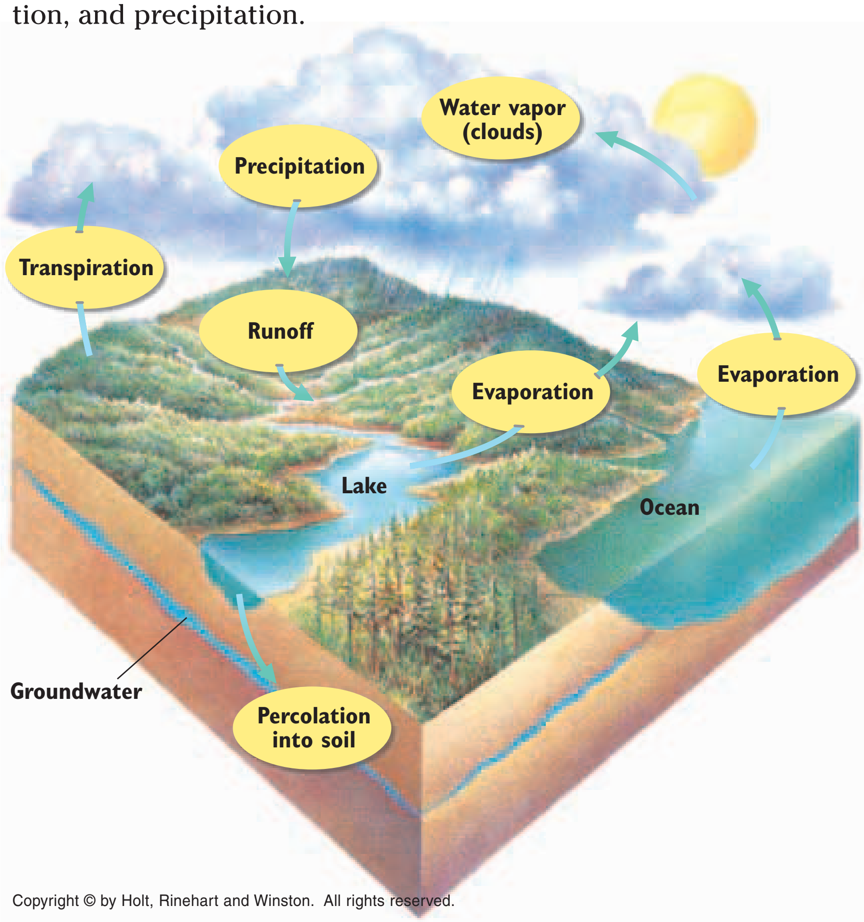

FIGURE 18-12

In the water cycle, water falls to Earth's surface as precipitation. Some water reenters the atmosphere by evaporation and transpiration. Some water runs into streams, lakes, rivers, and oceans. Other water seeps through the soil and becomes groundwater. Follow the pathways of the water cycle in the figure.

SECTION 4

OBJECTIVES

- **List** four major biogeochemical cycles.
- **Summarize** three important processes in the water cycle.
- **Outline** the major steps in the carbon cycle.
- **Describe** the role of decomposers in the nitrogen cycle.
- **Summarize** the major steps of the phosphorus cycle.

VOCABULARY

biogeochemical cycle
groundwater
water cycle
transpiration
carbon cycle
nitrogen cycle
nitrogen fixation
nitrogen-fixing bacteria
ammonification
nitrification
denitrification
phosphorus cycle

Quick Lab

Modeling Groundwater

Materials disposable gloves, lab apron, 3 L plastic bottle (cut in half), small stones (250 mL), dry sod with grass, water, graduated cylinder, 500 mL beaker

Procedure

1. Put on your lab apron, goggles, and disposable gloves.
2. Invert the top half of the plastic bottle, and place it inside the bottom half of the bottle to form a column.
3. Place the stones in the bottom of the inverted top half of the bottle. Place a chunk of dry sod with grass on top of the stones.
4. Pour 250 mL of water over the sod, and observe how the water penetrates the soil and moves through the column.
5. When the water is no longer draining, remove the top half of the column, and pour the water from the bottom of the column into a beaker. Measure the volume of liquid in the beaker.

Analysis What is the volume of the water that drained through the sod? How much of the water remained in the soil? Where does the water go when applied to a real lawn or crop? What might the fate of fertilizer or pesticides be that are applied to a lawn or crop?

Evaporation adds water as vapor to the atmosphere. Heat causes water to evaporate from bodies of water, from the soil, and from the bodies of living things. The process by which water evaporates from the leaves of plants in terrestrial ecosystems is called **transpiration.** Transpiration causes plants to take in water through their roots to replace the water that is being lost through their leaves. Animals also participate in the water cycle. Animals drink water or obtain it from their food. They release this water when they breathe, sweat, or excrete.

Water leaves the atmosphere through precipitation. The amount of water the atmosphere can hold depends on abiotic factors, such as temperature and air pressure. Once the atmosphere becomes saturated with water vapor, precipitation occurs in the form of rain, snow, sleet, hail, or fog.

THE CARBON CYCLE

Photosynthesis and cellular respiration form the basis of the short-term **carbon cycle,** illustrated in Figure 18-13. In photosynthesis, plants and other autotrophs use carbon dioxide (CO_2), along with water and solar energy, to make carbohydrates. Both autotrophs and heterotrophs use oxygen to break down carbohydrates during cellular respiration. The byproducts of cellular respiration are carbon dioxide and water. Decomposers release carbon dioxide into the atmosphere when they break down organic compounds.

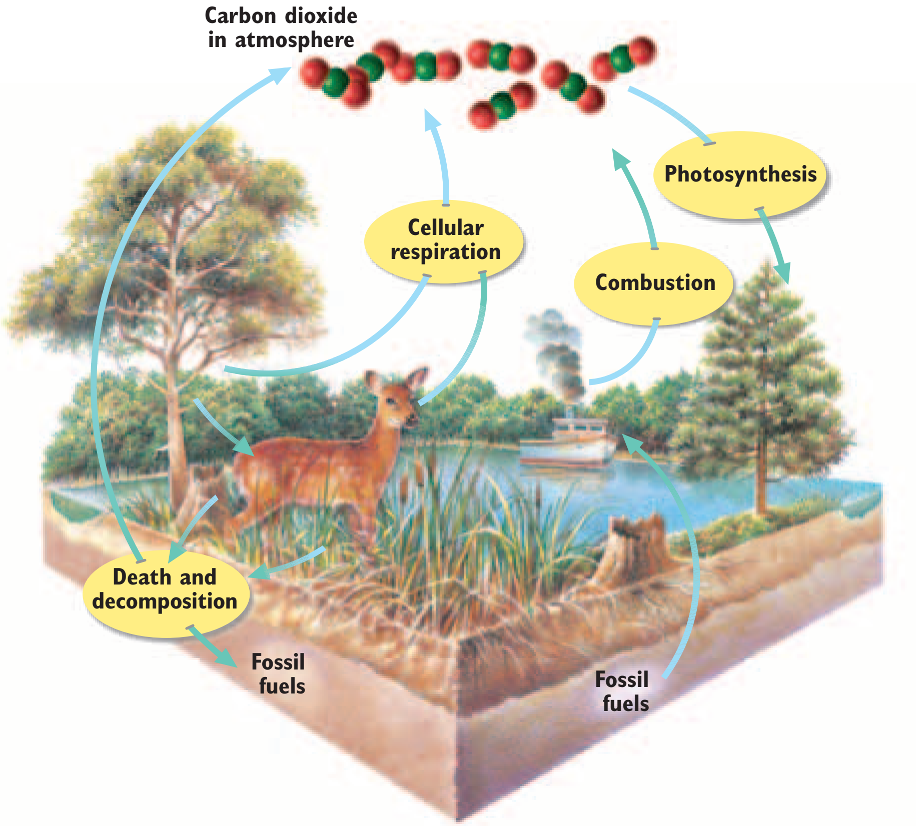

FIGURE 18-13

Carbon exists in the atmosphere as carbon dioxide. Cellular respiration, combustion, and decomposition of organic matter are the three major sources of carbon dioxide in the short-term carbon cycle. By burning large amounts of fossil fuels, humans are releasing carbon dioxide from a long-term reservoir and increasing the amount of carbon dioxide in the atmosphere.

Human Influences on the Carbon Cycle

In the last 150 years, the concentration of atmospheric carbon dioxide has risen more than 30 percent. Humans contribute to this increase by burning fossil fuels and other organic matter. Our industrial society depends on the energy released by the burning of fossil fuels—coal, oil, and natural gas. Fossil fuels are the remains of organisms that have been transformed by decay, heat, and pressure into energy-rich molecules. Burning releases the energy in these molecules, but it also releases carbon dioxide. When large areas of forest are burned each year to clear land for agriculture, less vegetation remains to absorb carbon dioxide from the atmosphere through photosynthesis.

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Topic: Cycles of Matter
Keyword: HM60373

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NITROGEN CYCLE

All organisms need nitrogen to make proteins and nucleic acids. The complex pathway that nitrogen follows in an ecosystem is called the **nitrogen cycle,** as shown in Figure 18-14. Nitrogen gas, N_2, makes up about 78 percent of the atmosphere, so it might seem that it would be readily available for living things. However, most plants can use nitrogen only in the form of nitrate. The process of converting N_2 gas to nitrate is called **nitrogen fixation.**

Most organisms rely on **nitrogen-fixing bacteria** to transform nitrogen gas into a usable form. These bacteria live in the soil and inside swellings on the roots of some kinds of plants, such as beans, peas, clover, and alfalfa. These plants supply carbohydrates for the bacteria, and the bacteria produce usable nitrogen for the plant. Additional nitrogen is released into the soil.

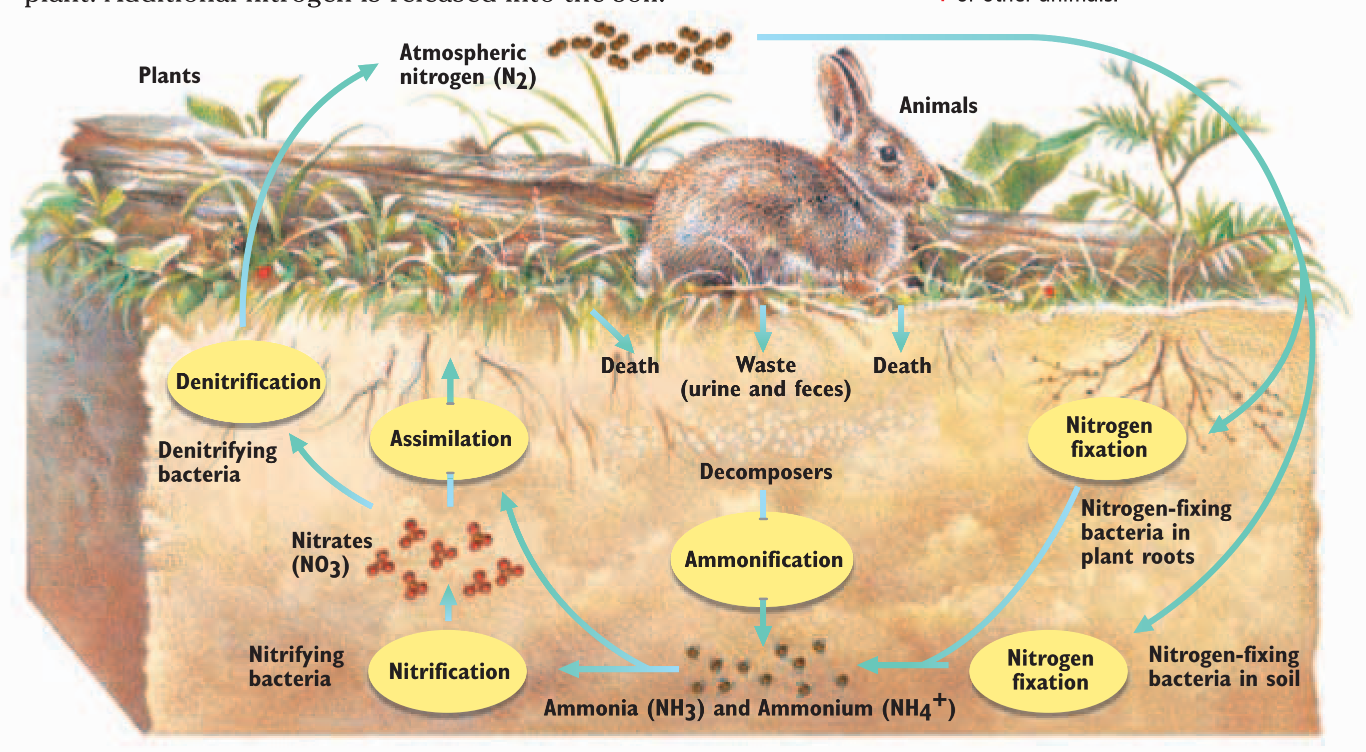


FIGURE 18-14
This figure shows the cycling of nitrogen within a terrestrial ecosystem. Bacteria are responsible for many of the steps in the nitrogen cycle, including the conversion of atmospheric nitrogen into ammonium. Nitrogen-fixing bacteria live in the soil or in the roots of plants. These bacteria convert nitrogen gas into ammonium. Other bacteria convert the ammonium into nitrates. Plants take up the nitrates produced by the bacteria. Animals get nitrogen by eating plants or other animals.

Recycling Nitrogen

The bodies of dead organisms contain nitrogen, mainly in proteins and nucleic acids. Urine and dung also contain nitrogen. Decomposers break down these materials and release the nitrogen they contain as ammonia, NH_3, which in soil becomes ammonium, NH_4^+. This process is known as **ammonification.** Through this process, nitrogen is again made available to other organisms.

Soil bacteria take up ammonium and oxidize it into nitrites, NO_2^-, and nitrates, NO_3^-, in a process called **nitrification.** The erosion of nitrate-rich rocks also releases nitrates into an ecosystem. Plants use nitrates to form amino acids. Nitrogen is returned to the atmosphere through **denitrification.** Denitrification occurs when anaerobic bacteria break down nitrates and release nitrogen gas into the atmosphere. Plants can absorb nitrates from the soil, but animals cannot. Animals obtain nitrogen in the same way they obtain energy—by eating plants and other organisms and then digesting the proteins and nucleic acids.

PHOSPHORUS CYCLE

Phosphorus is an element that is an essential material needed by animals to form bones, teeth, and parts of molecules, such as DNA and RNA. Plants get the phosphorus they need from soil and water, whereas animals get their phosphorus by eating plants or other animals. 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.

When rocks erode, small amounts of phosphorus dissolve as phosphate, PO_4^{3-}, in soil and water. Plants absorb phosphorus in the soil through their roots. Phosphorus is also added to soil and water when excess phosphorus is excreted in wastes from organisms and when organisms die and decompose. Some phosphorus applied to fields as fertilizer washes off the land into streams and groundwater.

SECTION 4 REVIEW

1. Identify four major biogeochemical cycles.
2. Through what process does most water vapor enter the atmosphere?
3. Outline the steps of the carbon cycle.
4. Describe the role of decomposers in the nitrogen cycle.
5. Identify the sources of phosphorus in the phosphorus cycle.

CRITICAL THINKING

6. **Inferring Relationships** How might the removal of vegetation affect oxygen levels in the atmosphere?
7. **Making Comparisons** Identify the role of bacteria in the carbon, nitrogen, and phosphorus cycles.
8. **Analyzing Concepts** Explain the statement that nutrients cycle, but energy flows.

CHAPTER HIGHLIGHTS

SECTION 1 Introduction to Ecology

- Species interact with both other species and their nonliving environment.
- Interdependence is a theme in ecology, and states that one change can affect all species in an ecosystem.
- Ecological models help to explain the environment.
- Ecology is usually organized into five levels: organism, population, community, ecosystem, and biosphere.

Vocabulary

ecology (p. 359)	**ecological model** (p. 360)	**ecosystem** (p. 362)	**population** (p. 362)
interdependence (p. 359)	**biosphere** (p. 361)	**community** (p. 362)	

SECTION 2 Ecology of Organisms

- Both biotic, or living, factors and abiotic, or nonliving, factors influence organisms. Examples of nonliving things are climate, sunlight, and pH.
- A niche is a way of life, or a role in an ecosystem.
- Some species survive unfavorable environmental conditions by becoming dormant or by migrating.

Vocabulary

habitat (p. 363)	**tolerance curve** (p. 363)	**regulator** (p. 364)	**niche** (p. 365)
biotic factor (p. 363)	**acclimation** (p. 364)	**dormancy** (p. 365)	**generalist** (p. 365)
abiotic factor (p. 363)	**conformer** (p. 364)	**migration** (p. 365)	**specialist** (p. 365)

SECTION 3 Energy Transfer

- Most producers are photosynthetic and make carbohydrates by using energy from the sun.
- Consumers obtain energy by eating other organisms and include herbivores, omnivores, carnivores, detritivores, and decomposers.
- Decomposers feed on dead organisms and wastes, which releases the nutrients back into the environment.
- A single pathway of energy transfer is a food chain. A network showing all paths of energy transfer is a food web.
- Ecosystems contain only a few trophic levels because there is a low rate of energy transfer between each level.

Vocabulary

producer (p. 366)	**biomass** (p. 366)	**herbivore** (p. 367)	**decomposer** (p. 367)
chemosynthesis (p. 366)	**net primary productivity** (p. 366)	**carnivore** (p. 367)	**trophic level** (p. 368)
gross primary productivity (p. 366)	**consumer** (p. 367)	**omnivore** (p. 367)	**food chain** (p. 368)
		detritivore (p. 367)	**food web** (p. 368)

SECTION 4 Ecosystem Recycling

- Key processes in the water cycle are evaporation, transpiration, and precipitation.
- Photosynthesis and cellular respiration are the two main steps in the carbon cycle.
- Nitrogen-fixing bacteria are important in the nitrogen cycle because they change nitrogen gas into a usable form of nitrogen for plants.
- Phosphorus moves from phosphate deposited in rock, to the soil, to living organisms, and finally to the ocean.

Vocabulary

biogeochemical cycle (p. 371)	**carbon cycle** (p. 372)	**nitrogen-fixing bacteria** (p. 373)	**nitrification** (p. 374)
groundwater (p. 371)	**nitrogen cycle** (p. 373)	**ammonification** (p. 374)	**denitrification** (p. 374)
water cycle (p. 371)	**nitrogen fixation** (p. 373)		**phosphorus cycle** (p. 374)
transpiration (p. 372)			

Using Vocabulary

1. For each pair of terms, explain how the meanings of the terms differ.
   a. *conformer* and *regulator*
   b. *community* and *ecosystem*
   c. *migration* and *dormancy*
   d. *nitrogen fixation* and *ammonification*
2. Use the following terms in the same sentence: *producer, consumer, herbivore, omnivore, carnivore, detritivore,* and *decomposer*.
3. **Word Roots and Origins** The word *transpiration* is derived from the Latin *trans*, which means "through," and *spirare,* which means "breathe." Using this information, explain why the term *transpiration* is a good name for the process it describes.

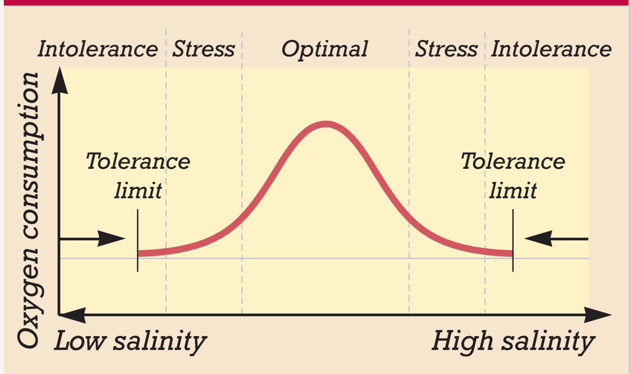
Understanding Key Concepts

4. **Explain** how an understanding of interdependence in ecosystems might be important to public health officials.
5. **Evaluate** how models are valuable to ecologists.
6. **Describe** some limitations of ecological models.
7. **Identify** five levels of organization in ecology.
8. **Propose** two examples of biotic factors and abiotic factors.
9. **Explain** the ecological concept of a niche.
10. **Distinguish** between conformers and regulators in how they deal with environmental change.
11. **Compare** photosynthetic and nonphotosynthetic producers.
12. **Distinguish** between a herbivore, a carnivore, and an omnivore.
13. **State** an example of each of the following: a herbivore, a carnivore, and an omnivore.
14. **Explain** the importance of decomposers in an ecosystem.
15. **Describe** why a food web is a more complete picture of the feeding relationships in an ecosystem than a food chain is.
16. **Identify** the reasons why most ecosystems normally contain only a few trophic levels.
17. **Compare** the transfer of energy with the transfer of nutrients in an ecosystem.
18. **Explain** how plants return water to the atmosphere as part of the water cycle.
19. **Describe** two processes in the carbon cycle.
20. **List** the mutual benefits in the association between nitrogen-fixing bacteria and the plants that they inhabit.
21. **Summarize** the phosphorus cycle.
22. **CONCEPT MAPPING** Use the following terms to create a concept map that shows some of the processes involved in the water cycle: *evaporation, precipitation, transpiration,* and *condensation*.

Critical Thinking

23. **Interpreting Graphics** Examine the diagram below of a tolerance curve. Briefly describe the conditions in each zone of tolerance and the reactions a species may have to them.

Salinity Tolerance Curve



24. **Relating Concepts** Nitrogen, water, phosphorus, and carbon are recycled and reused within an ecosystem, but energy is not. Explain why energy cannot be recycled.
25. **Drawing Conclusions** In the fall, many kinds of songbirds migrate from the United States to Central America or South America. Explain the benefits of migration for songbirds. What are some possible costs of this behavior?
26. **Analyzing Concepts** Ecologists have identified several characteristics that increase the likelihood that a species will become extinct. Specialization is one such characteristic. Explain why a very specialized species is likely to be more vulnerable to extinction.
27. **Making Models** Farmers often grow alfalfa, clover, or bean plants in fields after they have grown a grain crop. Explain this practice in terms of biochemistry.

Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. What are the levels of organization in ecology?
   A. cell, tissue, organ, organ system, body
   B. organ, organism, population, community
   C. organism, population, community, ecosystem, biosphere
   D. population, habitat, ecosystem, biogeochemical system, planet

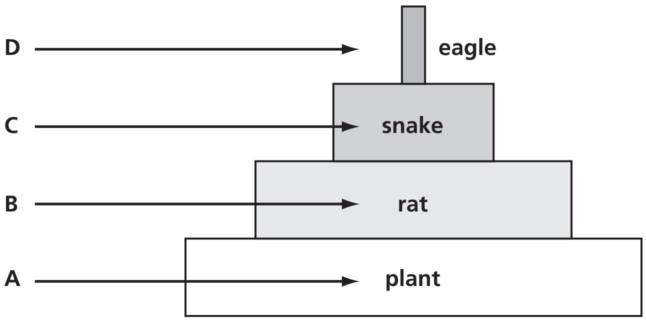
2. What makes up an ecosystem?
   F. all the habitat types on Earth
   G. all parts of Earth where life exists
   H. all members of a species in the same area
   J. all the living and nonliving factors in an environment

3. Which of the following are abiotic factors?
   A. plants
   B. animals
   C. sunlight
   D. microorganisms

4. How do decomposers benefit an ecosystem?
   F. by returning nutrients to the soil
   G. by manufacturing energy from sunlight
   H. by removing excess nutrients from the soil
   J. by removing predators from the ecosystem

5. Which organisms are most critical in the nitrogen cycle?
   A. plants
   B. nitrates
   C. animals
   D. bacteria

INTERPRETING GRAPHICS: The illustration below represents a trophic pyramid. Use the illustration to answer the question that follows.

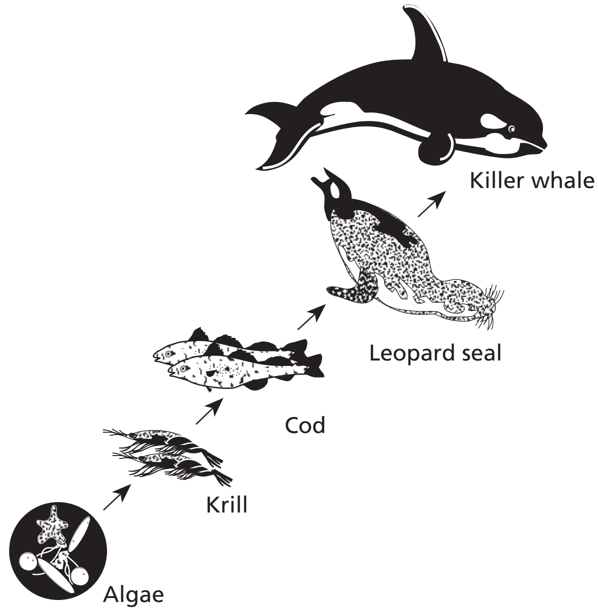


6. What is the term for the kinds of organisms that make up the trophic level labeled C?
   F. producers
   G. consumers
   H. detritivores
   J. decomposers

DIRECTIONS: Complete the following analogy.

7. bear : omnivore :: vulture :
   A. producer
   B. herbivore
   C. detritivore
   D. decomposer

INTERPRETING GRAPHICS: The illustration below represents a food chain. Use the illustration to answer the questions that follow.



8. What role do the krill have in this food chain?
   F. They are producers.
   G. They are consumers.
   H. They are detritivores.
   J. They are decomposers.

SHORT RESPONSE

Give two reasons why the destruction of tropical rain forests can contribute to an increase in carbon dioxide levels in the atmosphere.

EXTENDED RESPONSE

Some species are generalized with regard to their niche, and other species are specialized.

Part A Compare the niche of a generalist species with one of a specialist species.

Part B Predict how two different herbivores can share the same plant resource.

Test TIP If you are not sure about the spelling of certain words when answering the short or extended response questions, look at the question itself to see if the same word appears in the question.

Observing Habitat Selection

OBJECTIVES

- Assess the effect of light on habitat selection by brine shrimp.

PROCESS SKILLS

- observing
- measuring
- collecting data
- organizing data
- analyzing data

MATERIALS

- safety goggles
- marking pen
- clear, flexible plastic tubing (44 cm long)
- 4 test tubes with stoppers
- test-tube rack
- 2 corks to fit tubing
- graduated cylinder
- funnel
- brine shrimp culture
- aluminum foil
- 3 screw clamps
- 1 pipet
- Petri dish
- methyl cellulose
- fluorescent lamp or grow light
- 14 pieces of screen or thin cloth
- calculator

Background

1. Recall that a species' habitat is a specific area where it lives.
2. A species habitat selection depends on how well the location fits within the species' tolerance range. The more optimal all limiting factors are within a portion of an organism's range, the more likely the organism is to select that area for its habitat.
3. What limiting factors might be involved in habitat selection?
4. What is a niche?

PART A Setting Up

1. Mark the plastic tubing at 12 cm, 22 cm, and 32 cm from one end so that you will have the tube divided into four sections. Starting at one end, label the sections 1, 2, 3, and 4. Label four test tubes 1, 2, 3, and 4.
2. Place a cork in one end of the tubing. Use a graduated cylinder and a funnel to transfer about 50 mL of brine shrimp culture into the tubing. Cork the open end, and lay the tubing on the desktop.
3. You and your partner will complete either Part B or Part C and then share your results with the other students on your team. CAUTION **You will be working with live animals. Be sure to treat them gently and to follow directions carefully.**

PART B Control Group

1. Cover the tubing with aluminum foil, and let it remain undisturbed for 30 minutes. While you are waiting, create a data table like Table A, below, in your lab report to record the numbers of shrimp in each section of the tubing.

TABLE A CONTROL GROUP

Test tube number	Count 1	Count 2	Count 3	Count 4	Count 5	Average number of shrimp in test tube
1						
2						
3						
4						

2. After 30 minutes have passed, attach screw clamps to each spot that you marked on the tubing. While your partner holds the corks firmly in place, tighten the middle clamp first, and then tighten the outer clamps.
3. Immediately pour the contents of each section of tubing into the test tube labeled with the corresponding number.

4. **CAUTION Put on safety goggles before handling methyl cellulose. If you get methyl cellulose in your eyes, immediately flush it out at the eyewash station while calling to your teacher.** Stopper test tube 1, and invert it gently to distribute the shrimp. Use a pipet to draw a 1 mL sample of shrimp culture and transfer the culture to a Petri dish. Add a few drops of methyl cellulose to the Petri dish to slow down the shrimp. Count the live shrimp, and record the count in your lab report.
5. Dispose of the shrimp as your teacher directs. Repeat step 4 four more times for a total of five counts from test tube 1.
6. Calculate the average number of shrimp in test tube 1, and record the result in the data table you made in your lab report.
7. Repeat steps 4–6 for the contents of each of the remaining test tubes.
8. Clean up your materials, and wash your hands before leaving the lab.
9. In your lab report, make a histogram showing the total number of shrimp you counted in each section of tubing.

PART C Experimental Group

1. Set a fluorescent lamp 20 cm away from the tubing.
2. Cover section 1 of the tubing with eight layers of screen. Place four layers of screen on section 2 and two layers of screen on section 3. Leave section 4 uncovered. Leave this setup in place for 30 minutes. While you are waiting, create a data table in your lab report like Table B, below, to record the numbers of shrimp in each section of the tubing.

TABLE B EXPERIMENTAL GROUP

Test tube number	Count 1	Count 2	Count 3	Count 4	Count 5	Average number of shrimp in test tube
1						
2						
3						
4						

3. After 30 minutes have passed, attach screw clamps to each spot that you marked on the tubing. While your partner holds the corks firmly in place, tighten the middle clamp first, and then tighten the outer clamps.
4. Immediately pour the contents of each section of tubing into the test tube labeled with the corresponding number.
5. **CAUTION Put on safety goggles before handling methyl cellulose. If you get methyl cellulose in your eyes, immediately flush it out at the eyewash station while calling to your teacher.** Stopper test tube 1, and invert it gently to distribute the shrimp. Use a pipet to draw a 1 mL sample of shrimp culture and transfer the culture to a Petri dish. Add a few drops of methyl cellulose to the Petri dish to slow down the shrimp. Count the live shrimp, and record the count in your lab report.
6. Dispose of the shrimp as your teacher directs. Repeat step 5 four more times for a total of five counts from test tube 1.
7. Calculate the average number of shrimp in test tube 1, and record the result in the data table you made in your lab report.
8. Repeat steps 5–7 for the contents of each of the remaining test tubes.
9. Clean up your materials, and wash your hands before leaving the lab.
10. In your lab report, make a histogram showing the number of shrimp in each section of tubing. Identify each section with the amount of screen.

Analysis and Conclusions

1. Describe the differences between the histogram of the control group and the histogram of the experimental group.
2. Why was a control (Part B) necessary?
3. How did the brine shrimp react to differences in light? Justify your conclusion.

Further Inquiry

Design an experiment to test the reaction of brine shrimp to a gradient of heat.