Unit 5

ECOLOGY

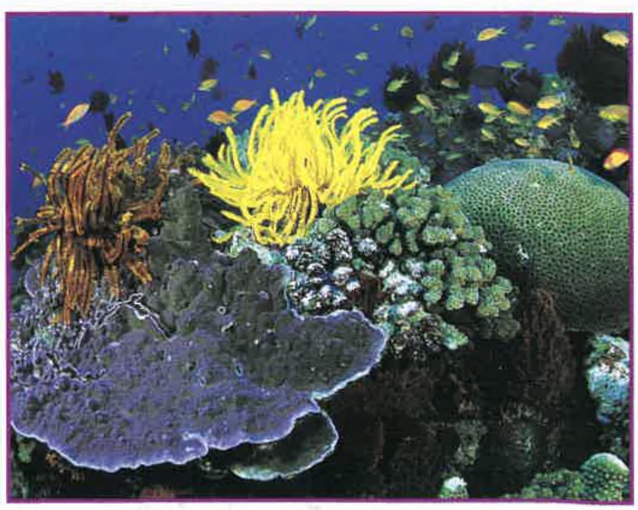
CHAPTERS

"We and our fellow vertebrates are largely along for the ride on this planet. If we want to perpetuate the dream that we are in charge of our destiny and that of our planet, it can only be by maintaining biological diversity—not by destroying it. In the end, we impoverish ourselves if we impoverish the biota."

internet**connect**

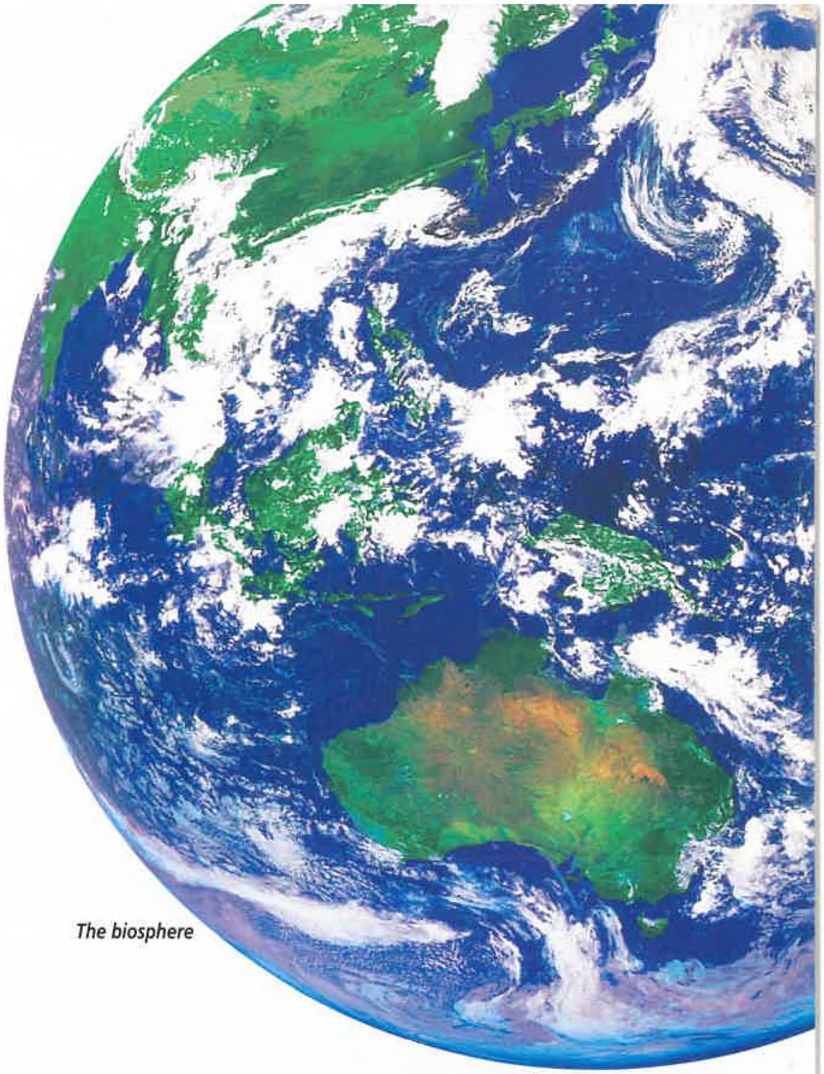
SCILINKS NSTA

National Science Teachers Association *sci*LINKS Internet resources are located throughout this unit.



Coral reef communities are second only to rain forests in diversity.

Bears are among the largest terrestrial predators.



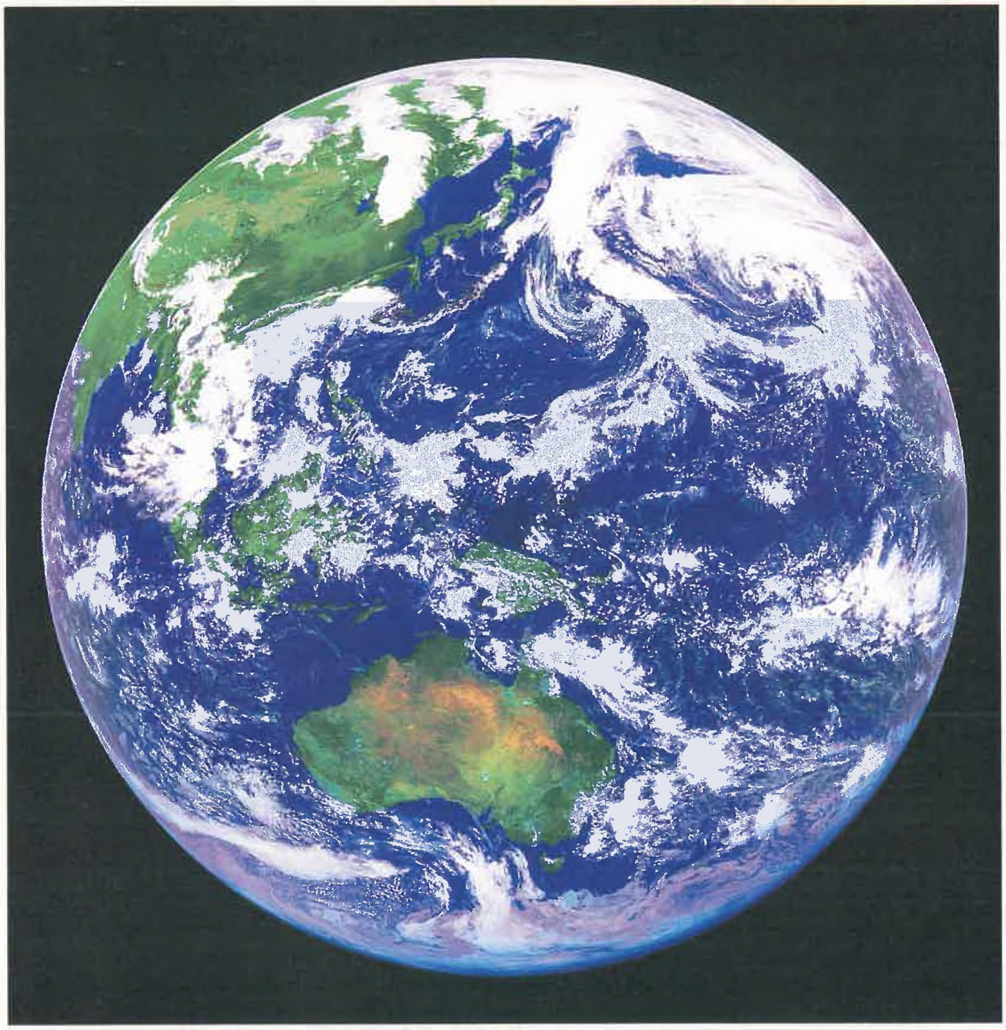
The biosphere

Mimicry helps this mantid hide from both predators and potential prey.

Tropical rain forests are richer in species than other areas of Earth.

CHAPTER 19

INTRODUCTION TO ECOLOGY



This is a view of the biosphere as seen from space.

FOCUS CONCEPT: ***Interdependence of Organisms***

As you read, notice that all organisms affect and are affected by the living and nonliving components of their environment.

ECOLOGY

Ecology *is the study of the interactions between organisms and the living and nonliving components of their environment. The Earth includes a tremendous variety of living things. Each organism depends in some way on other living and nonliving things in its environment. Ecology involves collecting information about organisms and their environments, looking for patterns, and seeking to explain these patterns.*

SECTION

19-1

OBJECTIVES

▲ Define the term *ecology,* and explain why ecology is important.

● List and describe three human-caused environmental problems.

■ Identify the five different levels of organization in ecology.

◆ Explain the theme of interconnectedness.

▲ Identify the importance of models to ecology.

TODAY'S ENVIRONMENT

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 grains, seeds, berries, nuts, and plants. For them, survival depended on practical knowledge about the environment. While our understanding of the environment has grown much more sophisticated, our need for information has grown more urgent. Over the past few decades, humans have changed the environment on a greater scale than ever before in history. Learning how to improve our effect on the environment is critical to the survival of our species.

The Exploding Human Population

The most significant environmental change is probably the rapid increase in the number of people on Earth. The world's human population has tripled from 2 billion in 1930 to 6 billion people in 1999. This increase in population is unprecedented in the history of our species. According to recent projections by the United Nations, in the year 2050 the world's population will be between 7.8 billion and 12.5 billion. Figure 19-1 on the following page shows that our present numbers are already causing severe crowding in some areas. An increasing population requires increasing amounts of energy, food, and space for the disposal of waste. Providing for the needs of this growing population will take an increasingly greater share of Earth's resources.

Word Roots and Origins

ecology

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

The Sixth Mass Extinction

As the human population has increased, many other species have declined in number or become extinct. For example, on the

FIGURE 19-1

Most of our planet is already very crowded, as this photograph of people in New York City shows. Scientists are concerned about how our quality of life will be affected if our population doubles within the next 50 years. If our population continues to grow at its present rate, the environment that supports us may collapse.

Hawaiian Islands, where isolation fostered the evolution of a diverse and unique set of species, 60 of the 100 species of native birds have disappeared since the first human colonists arrived. They were eliminated by habitat destruction, overhunting, and introduced diseases and predators. Two of these extinct birds are shown in Figure 19-2. Worldwide, about 20 percent of the species of birds have become extinct in the last 2,000 years. Today extinction is occurring most rapidly in the tropics.

Paleontologists have found evidence in the fossil record of five major mass extinctions, episodes in which a large percentage of Earth's species became extinct in a relatively short time. The sixth mass extinction is happening now. Currently, species are disappearing faster than at any time since the last mass extinction—the disappearance of the dinosaurs 65 million years ago. Scientists estimate that about one-fifth of the species in the world may disappear in just the next century.

FIGURE 19-2

The impact of humans has destroyed the habitats of many of the bird species native to the Hawaiian Islands. This destruction has caused the extinction of about 60 species of birds, including the birds shown below.

(a) Nukupu'u, *Heterorhynchus lucidus*

(b) Greater Koa, *Telespiza palmeri*

The Thinning Ozone Layer

The ozone layer in the upper atmosphere protects the living organisms on Earth by absorbing ultraviolet (UV) radiation from the sun. Industrial chemicals called chlorofluorocarbons (CFCs) and some related chemicals react with ozone and are destroying the ozone layer. In 1985, British scientists discovered an ozone "hole," a region of an abnormally low ozone level, over Antarctica, as shown in Figure 19-3. This discovery led to a treaty in 1992 to ban CFCs and other ozone-destroying chemicals.

Although ozone depletion is occurring to some degree over most of the planet, the reduction in the ozone level over Antarctica by 1996 was about 50 percent of its maximum density. About 1 percent of the UV radiation from the sun gets through the ozone shield to reach Earth's surface. That 1 percent is responsible for all sunburns and for more than a half-million skin cancers each year.

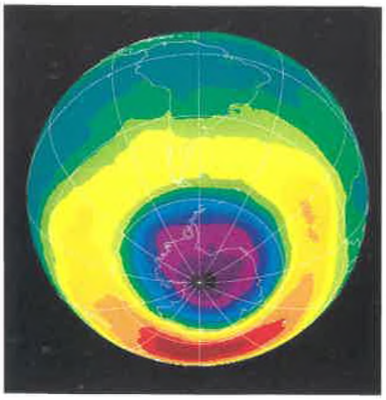


FIGURE 19-3

The ozone shield over Antarctica fluctuates in density seasonally, sometimes to a low of half the original density. The ozone shield is diminishing all over the planet as well.

Climatic Changes

Although carbon dioxide and water vapor are transparent to visible light, they intercept much of the reflected heat and direct it back toward Earth. This natural phenomenon, known as the **greenhouse effect,** is the mechanism that insulates Earth from the deep freeze of space. However, human activities are changing the composition of the atmosphere and thereby influencing climate. One prediction of possible future changes in climate is shown in Figure 19-4. When fossil fuels, such as coal, oil, and natural gas, are burned to provide energy, carbon dioxide is released. The burning of large amounts of fossil fuels has caused the concentration of carbon dioxide in the atmosphere to increase by about 25 percent in the last 100 years. A

FIGURE 19-4

The regions of the world that are likely to become wetter or drier as a result of global warming are shown below. Global warming and changes in rainfall are likely to be variable and unpredictable, so predictions cannot be entirely accurate. Predictions for the darker colored areas have a higher probability of being correct.

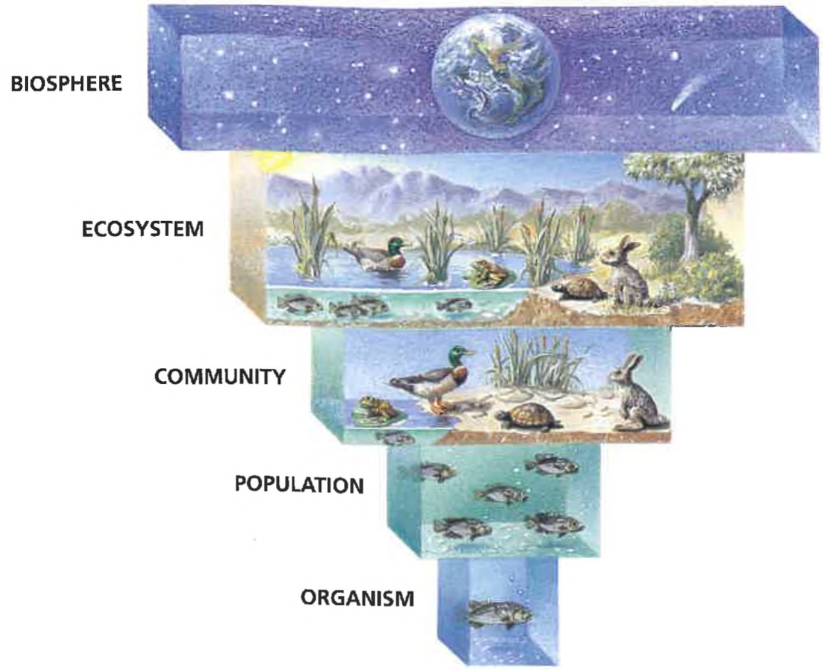


FIGURE 19-5

Ecology has been organized into several levels because of the complexity of the science.

Quick Lab

Modeling the Greenhouse Effect

Materials 1 qt jars (2), graduated cylinder, aluminum foil, transparent tape, thermometer, water

Procedure

1. Put 750 mL of cold tap water in each jar.
2. Measure and record the initial water temperature in each jar, and record the time it was measured.
3. Cover one jar with a single layer of aluminum foil, and secure the foil with tape. Leave the top of the other jar uncovered.
4. Place both jars in the same sunny window or under a plant light.
5. Before the end of the class period, record the temperature of the water in each jar and the time it was measured.

Analysis Did you discover a temperature difference between the jars when you measured the temperatures the second time? If so, which jar of water was warmer? How does this activity model the greenhouse effect?

global warming of the atmosphere is now occurring because of heat trapped by excess "greenhouse" gases, such as carbon dioxide.

Since 1860, the average global temperature has risen about 0.6°C (1°F), and most scientists agree that this increase was caused by higher levels of carbon dioxide in the atmosphere. Furthermore, scientists project that the average global temperature will increase 1.5°C to 4.5°C (3°F to 8°F) by the year 2100. This increase in average temperature may change global weather patterns and cause rising sea levels due to melting polar icecaps.

Ecological knowledge is essential for solving environmental problems. However, any proposed solution to an environmental problem must draw on knowledge from a variety of fields, including ecology, chemistry, physics, and geology, and it must take into account economic and political realities.

LEVELS OF ORGANIZATION

Scientists recognize a hierarchy of different levels of organization within organisms. Each organism is composed of one or more cells. Each cell is composed of molecules, which in turn are composed of atoms, and so on. Likewise, ecologists recognize a hierarchy of organization in the environment, as illustrated in Figure 19-5.

Each level has unique properties that result from interactions among its components, and these unique properties cannot be identified simply by studying lower levels in the hierarchy. For practical reasons, ecologists often focus their research on one level of organization. But they also recognize that each level is influenced by processes at other levels.

The Biosphere

The broadest, most inclusive level of organization is the **biosphere** (BIE-oh-SFEER), 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. Most organisms are found within a few meters of the surface of the land or oceans.

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—how much dissolved oxygen and carbon dioxide it contains, its supply of nitrogen, its pH—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.

Communities, Populations, and Organisms

While an ecosystem contains both the living and nonliving components, a community includes only 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 meaning in everyday speech.

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.

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.

Eco Connection

Global Warming and Disease

Ecologists are working with climatologists to investigate the relationship between climatic changes caused by global warming and the outbreak of disease.

In 1993, a virus began killing young people in the southwestern United States. An unusually mild winter and a wet spring sent piñon trees blooming, providing virus-carrying mice with a plentiful supply of pine nuts. The mice population increased tenfold. The abundant mice found their way into people's homes and spread the virus to humans. Half the people infected with the virus died.

Several of the deadliest diseases known, such as malaria, yellow fever, and encephalitis, are carried by mosquitoes, whose population levels are affected by even small changes in temperature and rainfall. Researchers are carefully monitoring mosquitoes, mice, and other disease carriers and charting climatic changes in an effort to predict if, when, and where the next outbreak of disease might occur.

internet**connect**

SCILINKS NSTA

TOPIC: Global warming
GO TO: www.scilinks.org
KEYWORD: HM363

A KEY THEME IN ECOLOGY

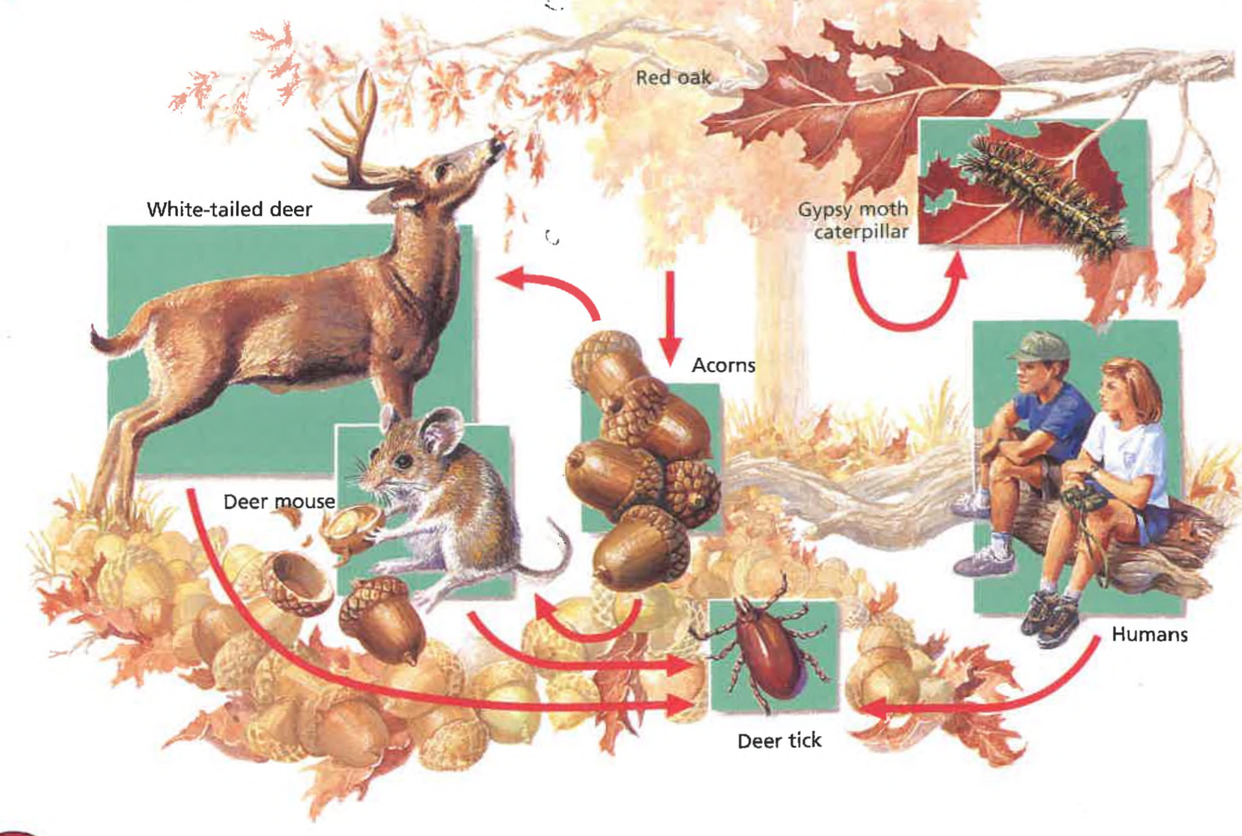
An important fact to keep in mind as you study ecology is that no organism is isolated. The theme of the interconnectedness of all organisms is central to the study of ecology. All organisms interact with other organisms in their surroundings and with the nonliving portion of their environment. Their survival depends on these interactions. Thus, each ecosystem is a network in which organisms are linked to other organisms and to the nonliving environment. Ecologists refer to this quality as interconnectedness or interdependence. 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.

Disturbances in Ecosystems

An important consequence of interconnectedness is that any disturbance or change in an ecosystem can spread through the network of interactions and affect the ecosystem in widespread and often unexpected ways. To see one example, look at Figure 19-6, which shows some of the interrelationships among species in an oak forest. The number of people who get sick with Lyme disease,

FIGURE 19-6

All of the very different species shown are ecologically connected in the forest. An unusually plentiful crop of acorns helps support a large population of deer and mice, which help support a large population of ticks. Ticks carry the bacterium that causes Lyme disease. They pass on the disease to humans who visit the forest.



a bacterial infection that can damage the nervous system, is related to acorn production in forests in the eastern United States.

Oak trees typically produce few acorns (or none at all) in most years. Every few years, however, they produce a huge crop of acorns, setting off a chain of events within the ecosystem. The abundance of acorns enables deer and mice, which feed on acorns, to have more offspring that survive, and their populations grow. More deer and mice can support more ticks, so the tick population also increases. Lyme disease is spread by the bite of the deer tick. The number of people bitten by ticks (and potentially exposed to Lyme disease) depends on the number of ticks and the number of people in the forest. In general, as the population of ticks increases, the number of Lyme disease cases increases.

internetconnect
SCiLINKS NSTA
TOPIC: Threats to ecosystems
GO TO: www.scilinks.org
KEYWORD: HM365

ECOLOGICAL MODELS

Ecological knowledge is vital, but ecosystems are extremely complex and difficult to study. One way that ecologists deal with this complexity is to use models. A model may be visual, verbal, or mathematical. An ecologist might use a graphical model to show how sunlight, rainfall, and temperature affect the growth of plants. Ecologists construct models to help them understand the environment and to make predictions about how the environment might change. Figure 19-4 is a model based on scientific predictions about how climates may change. In ecology, models are typically expressed as graphs, diagrams, or mathematical equations. Figure 19-5 is a model in the form of a diagram.

A model can be used to test a hypothesis about an ecosystem. Scientists use models to make predictions about the future behavior of the ecosystem, and 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. It is important to keep in mind, however, that models are simplified systems designed only to mimic the behavior of the natural world. A model is limited in its application, therefore, because it cannot account for the influence of every variable in a real environment.

SECTION 19-1 REVIEW

1. Why was knowledge about the environment important to the earliest members of our species? Why is such knowledge important now?
2. What is causing the thinning of the ozone layer?
3. How does a population differ from a community?
4. Describe one example of interdependence.
5. Why are models so useful in ecology?
6. CRITICAL THINKING Why is it important to understand challenges in a species' environment in order to understand the species' evolution? Relate your answer to what Darwin referred to as "the struggle for survival."

GREAT DISCOVERIES

The Rise and Fall of Island Species

HISTORICAL PERSPECTIVE

In the mid-1800s, Charles Darwin observed and collected organisms in the Galápagos Islands. His fieldwork led to the theory of natural selection as a mechanism for evolution. About a century later, mathematician and ecologist Robert H. MacArthur also studied species found on islands. With taxonomist and zoogeographer Edward O. Wilson, MacArthur developed the theory that provided the title to their book,* The Theory of Island Biogeography. *Biogeography is the study of the geographical distribution of plants and animals. Today this field has increasing relevance for ecologists and for all who care about the survival of species.

A Project in Biogeography

By the mid-1950s, Edward O. Wilson had studied insect species he had found on a number of islands. His specialty was myrmecology, the biology of ants. After many years of study and fieldwork, Wilson wanted to go beyond the simple collection and description of organisms, a desire that meshed well with the thinking of Robert H. MacArthur.

MacArthur began his career as a mathematician, but he later moved to mathematical ecology. He was interested in patterns and ideas and in a bigger picture of nature. He wanted to understand the fundamental principles in the science of ecology.

MacArthur and Wilson each brought specific strengths to the field of biogeography. Soon after the two men met, in 1959, they began the project that led to their book. In their book, MacArthur and Wilson explain why they chose to concentrate on the study of species on islands: "In the science of biogeography, the island is the first unit that the mind can pick out and begin to comprehend."

Robert H. MacArthur and Edward O. Wilson

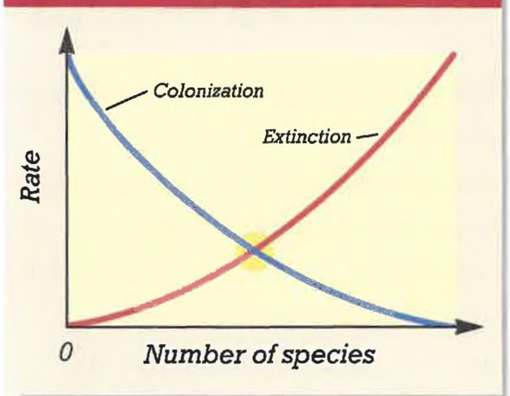
Seeing the Patterns

Wilson noticed that the number of ant species on an island tends to 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, which, in this context, means that they cease to exist on the island. However, the total number of ant species remains constant. Wilson and MacArthur called that constant number of species an equilibrium.

When they examined the data closely, MacArthur and Wilson found that the same pattern exists among bird species in the Philippines, Indonesia, and New Guinea. In each case, when one species of animal disappeared from an island, a new one moved in, but the total number of species remained constant.

MacArthur and Wilson graphed their data, as shown on the facing page. The downward slope of the immigration (colonization) line shows that the number of species

Colonization Versus Extinction



This simple model represents the equilibrium of numbers of island species. Note that the rate of colonization is highest when the number of species is lowest, as shown on the model at the y-axis. The rate of extinction is highest and the rate of colonization is lowest when the number of species is at a maximum. At what point are the rates of colonization and extinction equal?

that moved in decreased as the island became crowded. That is, the rate of colonization slowed with an increase in the number of species. The upward slope of the extinction line shows that as the island grew more crowded, more species became extinct. In other words, the rate of extinction increased with an increase in the number of species. The crossing point is an equilibrium, the constant number of species for that island.

Constructing 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.
2. Remote islands—those located far from the mainland or from a larger island—have fewer species than less-remote ones.

Earlier biogeographers had explained these phenomena from a historical perspective. They reasoned, for example, that a remote island took eons to fill up with species, so an island with few species probably has a relatively short history. In MacArthur and Wilson's model, size and isolation—not the age of the island—regulate the number of immigrations and extinctions.

Testing and Predicting

Could their model be used to predict the number of species on an island? MacArthur and Wilson decided to test their model on Krakatau, an island in Indonesia on which a volcano had erupted in 1883, killing every living thing on the island. The eruption left Krakatau much like a newborn island. Equally important, the return of plant and animal life to the island had been carefully recorded since Krakatau was first revisited, in 1886.

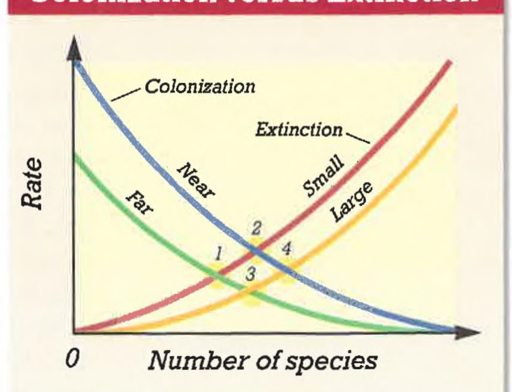
Using their model, MacArthur and Wilson predicted that at the point of equilibrium, the number of bird species would be about 30. After examining the records of bird life at Krakatau, they learned that their prediction had come close. The number of species had climbed to 27 before leveling off. Five species were new to the island, but an equal number had become extinct, maintaining the equilibrium number of 27.

New Ways of Thinking

The response from other scientists to *The Theory of Island Biogeography,* published in 1967, was mixed. At the very least, the theory introduced in the book has stimulated further research in the field of biogeography. This in turn has led to increased knowledge about how an environment's geography affects its ecology. MacArthur and Wilson looked beyond isolated facts and events to investigate similarities, patterns, and ongoing processes. By reflecting on the larger picture, perhaps biogeographers can help increase awareness of the importance of biodiversity.

This model shows effects that the size and remoteness of an island have on species equilibrium. Note that far (remote), small islands reach an equilibrium (shown at 1) with fewer species than near, large islands (shown at 4).

Colonization Versus Extinction



SECTION

19-2

OBJECTIVES

▲ Contrast abiotic factors with biotic factors, and list two examples of each.

● Explain the importance of tolerance curves.

■ Describe some adaptations that allow organisms to avoid unfavorable conditions.

◆ Explain the concept of the niche.

▲ Contrast the fundamental niche with the realized niche.

ECOLOGY OF ORGANISMS

Some basic questions to ask about an organism are, Where does it live? and Why does it live there? The answers to these questions are complex and involve the organism's evolutionary history, its tolerances and requirements, the history and conditions of its ***habitat*** *(where it lives), and many other factors. In this section you will study how environments affect the distribution of organisms and how organisms respond to their environments.*

BIOTIC AND ABIOTIC FACTORS

Ecologists separate the environmental factors that influence an organism into two classes. 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. Important 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 compounds from the soil.

The Changing Environment

Abiotic factors are not constant. They vary from place to place and over time, as shown in Figure 19-7. Consider temperature, which is probably the most important abiotic factor. Temperature changes on several different scales. It varies from hour to hour, from day to day, from season to season, and from year to year. A glance at a weather map in the newspaper will confirm that temperature also varies from place to place in a predictable way. Phoenix is usually warmer than Los Angeles and nearly always warmer than Seattle. Also important to organisms 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 19-7

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

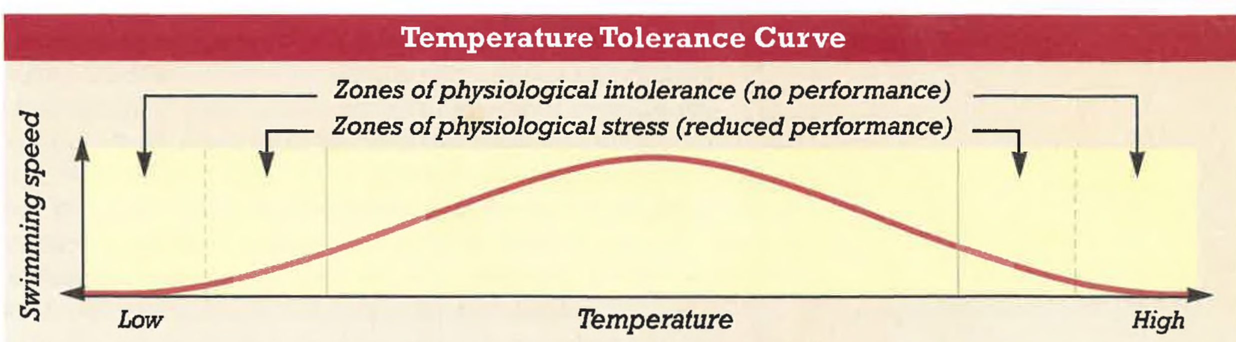
Responses to a Changing Environment

Organisms are able to survive within a wide range of environmental conditions. Some heat-tolerant bacteria live far below Earth's surface at temperatures as high as 110°C (230°F), while some plants can withstand temperatures as low as −70°C (−94°F). However, no single organism can survive both of these extremes. Rather, organisms are adapted to function 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 19-8 shows a tolerance curve for a species of fish. Here, performance was measured by the fish's maximum possible swimming speed. Notice that the fish's swimming speed is highest at intermediate temperatures, within what is called its optimal range. The fish can survive and function at temperatures outside its optimal range, but its performance is greatly reduced. The fish cannot survive outside its tolerance limits.

An organism cannot live in areas where it is exposed to conditions that fall outside its tolerance limits. In some cases, an organism's range may be determined by its tolerance to just one factor, such as temperature. In most cases, however, the levels of several factors, such as pH, temperature, and salinity, must fall within the organism's tolerance range.

FIGURE 19-8

The tolerance curve below shows that fish are capable of swimming fastest when the temperature of the water is within their optimal range. When the water is too warm or too cool, the fish are stressed and may not survive.



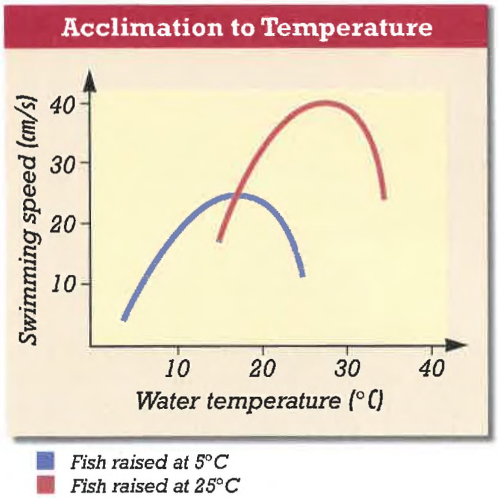
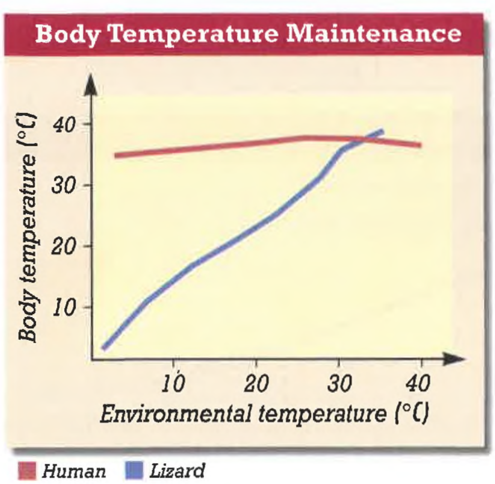


FIGURE 19-9

Fish raised at 25°C are acclimated to higher temperatures and are able to tolerate much warmer temperatures than the fish raised at 5°C.

FIGURE 19-10

An organism can be a regulator or a conformer, or both. The lizard, represented by the blue line, is a conformer with regard to body temperature, whereas humans, represented by the red line, regulate internal temperature.



Acclimation

Some organisms can adjust their tolerance to abiotic factors through the process of **acclimation** (AK-luh-MAY-shuhn). For instance, goldfish raised at different temperatures have somewhat different tolerance curves, as shown in Figure 19-9. If you spend a few weeks at a high elevation, you will acclimate to reduced oxygen levels, or "thin air." Over time, the number of red blood cells in your body will increase, thereby increasing the amount of oxygen your blood can carry. 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 over many generations.

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. For example, the body temperature of desert lizards rises and falls with the temperature of the lizards' environment, as shown in Figure 19-10. 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. Your body temperature, for instance, remains within a few degrees of 37°C (99°F) throughout the day. Pacific salmon, which spend part of their lives in salt water and part in fresh water, are conformers to environmental temperatures but are regulators of their internal salt concentration.

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 environmental conditions. Throughout most of the United States, winter temperatures are too cold for reptiles and amphibians to tolerate, but these animals survive by hiding underground and becoming dormant until spring. Another strategy is to move to another, more favorable habitat. This is called **migration.** A familiar example of migration is the seasonal movements of birds, which spend spring and summer in cooler climates

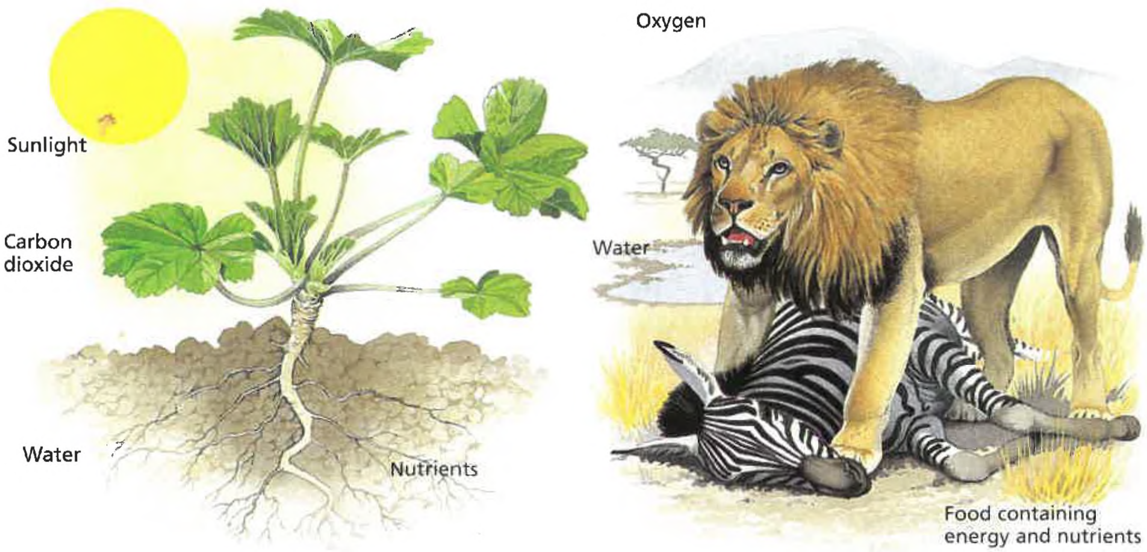


FIGURE 19-11

Plants and animals are able to share the same spaces because they each have different requirements for survival.

and then migrate to warmer climates in the fall. They remain in the warmer climate until spring, when they return to the cooler climate. Birds thus avoid the low temperatures and food scarcity of winter.

Resources

Whether a species can survive in a particular habitat depends on the suitability of environmental conditions and also on the availability of **resources,** the energy and materials the species needs. Food, energy, nesting sites, water, and sunlight are examples of resources that are often required by animals or plants. The resources essential for survival differ from species to species. As you can see in Figure 19-11, plants require a very different set of resources than animals do.

THE NICHE

A species' **niche** (NICH) is its way of life, or the role the species plays in its environment. The niche includes the range of conditions that the species can tolerate, the methods by which it obtains needed resources, the number of offspring it has, its time of reproduction, and all of its other interactions with its environment. When studying the niche of a species, scientists usually concentrate on a few features that can be readily measured, such as where the species lives, what time of day it is active, and what it eats. Figure 19-12 shows an aspect of the feeding behavior of a common species of songbird.

The **fundamental niche** is the range of conditions that a species can potentially tolerate and the range of resources it can potentially use. In reality,

FIGURE 19-12

The graph below illustrates the blue-gray gnatcatcher's feeding behavior. The darkest shade in the center of the contour lines indicates that most prey are captured between 3 m and 5 m above ground. The prey most frequently captured averaged about 4 mm in length.

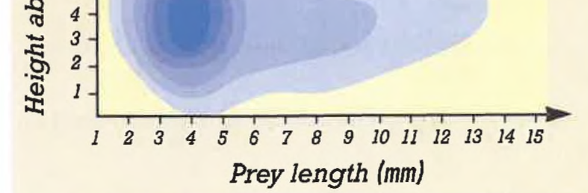
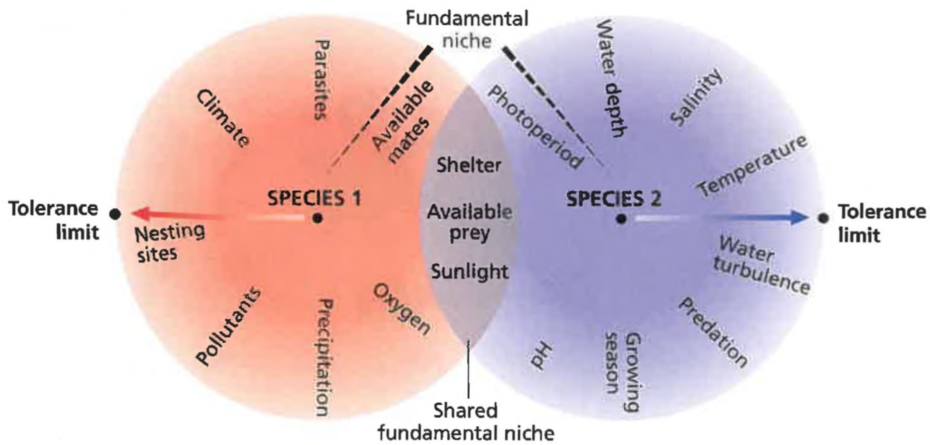


FIGURE 19-13

Each of these circles represents the fundamental and realized niche of a species. The center of each circle represents optimal conditions. Farther from the center, conditions are less ideal. Note that the fundamental niches can overlap but the realized niches cannot. Ecologically similar species do not occupy the same realized niche.



internet**connect**

SCILINKS NSTA
TOPIC: Niches
GO TO: www.scilinks.org
KEYWORD: HM372

a species may have to restrict its activity to avoid predators, or competition with other species may prevent it from using a resource. The **realized niche** of a species is the range of resources it actually uses. The fundamental niche will usually include a much broader set of conditions than the realized niche. The darkest blue area in Figure 19-12 indicates a realized niche. The progressively lighter shades indicate increasing intolerance to environmental conditions as the birds' niche changes from realized to fundamental.

Niche Differences

A species' niche can change within a single generation. For example, caterpillars eat the leaves of plants. After feeding for some time, they transform into butterflies, which feed on nectar.

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

Word Roots and Origins

niche

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

SECTION 19-2 REVIEW

1. List three abiotic factors that can affect an organism.
2. What does a tolerance curve indicate about an organism?
3. What is migration? Give an example of migration.
4. How is an organism's niche different from its habitat?
5. List two factors that might cause an organism to restrict its use of a resource.
6. CRITICAL THINKING Explain why two different species do not occupy exactly the same niche.

CHAPTER 19 REVIEW

SUMMARY/VOCABULARY

19-1

- Ecology is the study of the relationships between organisms and their environment, including both the living and nonliving components.
- Ecological knowledge was crucial to the survival of our early human ancestors. Ecology is essential today because humans are changing the world rapidly and on a global scale.
- The human population is growing extremely rapidly. It has tripled in size in about 70 years.
- Rapid growth of the human population has caused the extinction of many other species of organisms. The rate of extinction today is higher than at any time since the extinction of the dinosaurs.
- Industrial chemicals released into the atmosphere are destroying the ozone layer, the protective shield around Earth that absorbs harmful ultraviolet radiation from the sun.
- Burning of fossil fuels has increased atmospheric levels of carbon dioxide. Most scientists think this is causing global warming, or a rise in global temperatures.
- The science of ecology is usually organized into five levels, each of which has unique properties: organism, population, community, ecosystem, and biosphere.
- Species in ecosystems interact with other species and with their nonliving environment. As a result, a disturbance that affects one species can spread to other species in the ecosystem.
- Because ecosystems are so complex, ecologists rely on models, simplified systems that mimic the behavior of the natural world.

Vocabulary

biosphere (363)
community (363)
ecology (359)
ecosystem (363)
greenhouse effect (361)
population (363)

19-2

- An organism's habitat is where it lives.
- Two kinds of factors influence organisms: biotic factors, which are living things, and abiotic factors, which are nonliving things or processes, such as climate, sunlight, and pH.
- The environment changes over time and from place to place.
- Each organism can tolerate a range of environmental conditions. A graph showing this range is called a tolerance curve.
- Over a short period of time, organisms can adjust their tolerance curves through the process of acclimation.
- Species follow two strategies in dealing with environmental change. Regulators control their internal conditions, while conformers' internal conditions vary with the environment.
- Species often escape unfavorable environmental conditions by migrating to a new habitat or by becoming dormant and waiting out the unfavorable conditions.
- A species' niche is its way of life, or its role in an ecosystem.
- A species' fundamental niche is the range of conditions that it can potentially tolerate and the resources that it can potentially use. In the face of competition or predation, a species may use a smaller range of resources or live in a reduced range of conditions. These actual resources used and conditions best tolerated make up a species' realized niche.
- Species with broad niches are called generalists, while species with narrow niches are called specialists.

Vocabulary

abiotic factor (368)
acclimation (370)
biotic factor (368)
conformer (370)
dormancy (370)
fundamental niche (371)
generalist (372)
habitat (368)
migration (370)
niche (371)
realized niche (372)
regulator (370)
resource (371)
specialist (372)
tolerance curve (369)

REVIEW

Vocabulary

1. Define the term *ecology.*
2. How is a community different from an ecosystem?
3. List two abiotic factors that influence you.
4. In what way is migration similar to dormancy?
5. Distinguish between regulators and conformers.

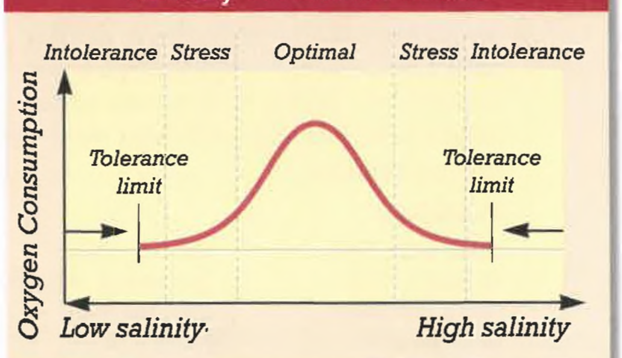
Multiple Choice

6. The number of species on Earth (a) is exactly 1.5 million (b) has increased over the last 2,000 years (c) is smaller than the number that occurred during the time of the dinosaurs (d) is decreasing rapidly.
7. The thinning of the ozone layer is caused by (a) CFCs (b) carbon dioxide (c) oxygen gas (d) carbon monoxide.
8. Which of the following is not one of the five main levels of organization within ecology? (a) biosphere (b) ecosystem (c) atom (d) community (e) population
9. An ecosystem includes (a) all the members of one species (b) all the living and nonliving factors in an environment (c) all parts of Earth where life exists (d) all members of a species in the same area.
10. Which of the following is not true of models? (a) They are simplified systems that mimic the natural world. (b) They can be tested by comparison with real situations. (c) They help scientists make predictions. (d) They exactly duplicate reality.
11. Abiotic factors in an ecosystem can include (a) plants (b) animals (c) sunlight (d) micro-organisms.
12. An animal could migrate to avoid (a) a hurricane (b) cold temperatures in winter (c) an extreme cold snap (d) a volcanic eruption.
13. A species' fundamental niche (a) cannot be larger than its realized niche (b) changes in response to predators or competitors (c) can be larger or smaller than its realized niche (d) is always as large as or larger than its realized niche.
14. Which of the following is not a resource needed by animals? (a) water (b) food (c) carbon dioxide (d) oxygen
15. Which of the following is not true of an organism's tolerance for an environmental variable?
    (a) Its performance is usually best at intermediate values.
    (b) Its performance can be illustrated with a tolerance curve.
    (c) Its tolerance levels cannot vary over the organism's lifetime.
    (d) Tolerance levels can change through acclimation.

Short Answer

16. Explain how an understanding of interconnectedness in ecosystems might help a health official determine how much money to allocate for the treatment of people with Lyme disease.
17. Why are models so valuable to ecologists? What are some limitations of models?
18. The biotic and abiotic factors in an ecosystem can interact. Give two examples of such interactions.
19. What is a tolerance curve? What application does it have to ecology?
20. Give two examples of environmental conditions that bears avoid by hibernating in winter.
21. 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.
22. What is acclimation? How is acclimation different from adaptation by natural selection?

Salinity Tolerance Curve

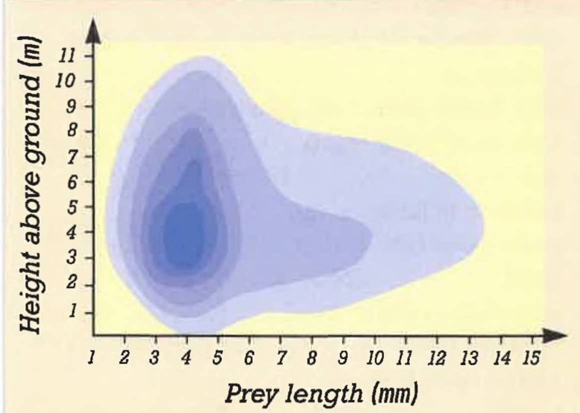


23. Describe two methods, not including acclimation, that organisms use to respond to unfavorable conditions in their environment.
24. Ecologically speaking, humans are considered generalists rather than specialists. Explain why.
25. What abiotic factors might account for differences in net primary productivity in ecosystems?

CRITICAL THINKING

1. 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 consequences of this behavior?
2. The gypsy moth is a destructive insect pest. In the ecosystem illustrated in Figure 19-6, the caterpillars of the gypsy moth negatively affect oak trees by consuming their leaves. The number of caterpillars in the forest fluctuates, and every few years the caterpillar population increases dramatically. Trace the effects that a large increase in the caterpillar population might have on the other members of this ecosystem. How might an increase in caterpillars affect the incidence of Lyme disease? Explain your answer.
3. 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.
4. Evaluate the following statement: Though the field of ecology had not been defined in Charles Darwin's day, Darwin was an ecologist.
5. Explain why scientists believe that ecology and evolution are tightly linked.
6. Study the diagram of the niche of a species of songbird below. Where does the bird capture most of its food? Which sizes of insects does it prefer?

Prey Size and Location



EXTENSION

1. Read "The Final Countdown" in *Audubon*, November–December 1999, on page 65. According to E. O. Wilson, how does biodiversity measure the value of an ecosystem? How will the loss of biodiversity affect human life?
2. Pick a small outdoor area—a lawn, or window box. With a string, mark off a 1,000 cm^2 area and carefully count the plants and animals found there. Note the number of species found, and identify as many as you can. Compare your findings with those of your classmates.
3. Using library resources or an on-line database, research the Biosphere 2 project. What is Biosphere 2, and where is it located? What were the goals and outcomes of the first two-year experiment in Biosphere 2? What scientific criticisms were leveled at the project?

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 screening
- 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 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 screening. Place four layers of screening on section 2 and two layers of screening 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 EFFECTS OF LIGHT ON BRINE SHRIMP

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 screening.

Analysis and Conclusions

1. How did the brine shrimp react to the changes in light?
2. Why was a control (Part B) necessary?
3. How do the histograms made by different groups compare?

Further Inquiry

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

CHAPTER 20

POPULATIONS

This is part of a population of bottlenose dolphins, Tursiops truncatus.

FOCUS CONCEPT: ***Interdependence of Organisms***

As you read the chapter, notice how even very simple models can help you understand population processes.

UNDERSTANDING POPULATIONS

The human population of the world was about 6 billion in 1996, three times its size in 1900. During this period of rapid human population growth, populations of many other species have decreased dramatically. Will the human population continue to grow? Will populations of other species continue to get smaller? Will other species continue to become extinct? An understanding of populations is crucial to answering these questions.

SECTION

20-1

OBJECTIVES

▲ Explain the differences between population size, density, and dispersion.

● Describe the three main patterns of population dispersion.

■ Explain the importance of a population's age structure.

◆ Contrast the three main types of survivorship curves.

PROPERTIES OF POPULATIONS

A population is a group of organisms that belong to the same species and live in a particular place at the same time. All of the bass living in a pond during a certain period of time constitute a population because they are isolated in the pond and do not interact with bass living in other ponds. The boundaries of a population may be imposed by a feature of the environment, such as a lake shore, or they can be arbitrarily chosen to simplify a study of the population.

The properties of populations differ from those of individuals. An individual may be born, it may reproduce, or it may die. A population study focuses on a population as a whole—how many individuals are born, how many die, and so on.

Population Size

A population's size is the number of individuals it contains. Size is a fundamental and important population property, but it can be difficult to measure directly. If a population is small and composed of immobile organisms, such as plants, its size can be determined simply by counting individuals. More often, though, individuals are too abundant, too widespread, or too mobile to be easily counted, and scientists must estimate the number of individuals in the population. Suppose that a scientist wants to know how many oak trees live in a 10 km^2 patch of forest. Instead of searching the entire patch and counting all the oak trees, the scientist could count the trees in a smaller section of the forest, such as a 1 km^2 area, and use this

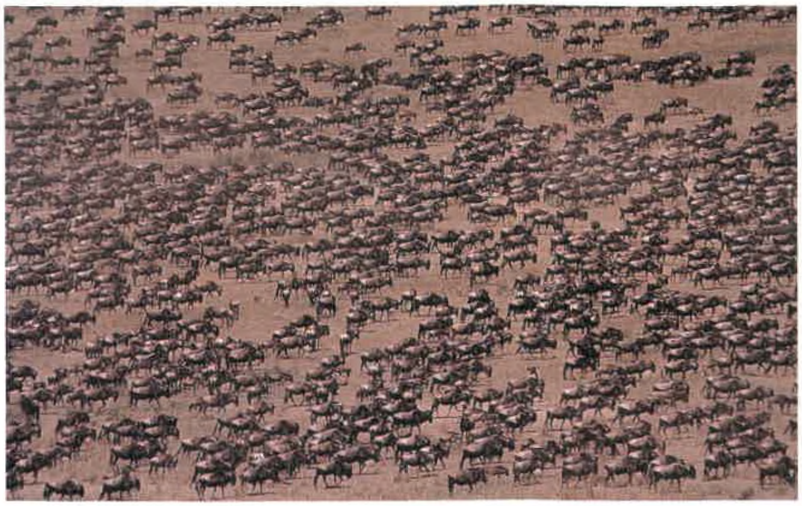


FIGURE 20-1

These migrating wildebeests in East Africa are too numerous and mobile to be counted. Scientists must use sampling methods at several locations to monitor changes in the population size of the animals.

value to estimate the population of the larger area. If the small patch contains 25 oaks, an area 10 times larger likely would contain 10 times as many oak trees, so a reasonable estimate for the population's size is 250 oak trees. A similar kind of sampling technique must be used to estimate the size of the population shown in Figure 20-1.

This kind of estimate assumes that the distribution of trees in the forest is the same as that of the sampled patch. If this assumption is not accurate, the estimate will be inaccurate. Estimates of population size are based on certain key assumptions, so they all have the potential for error.

Population Density

Population density measures how crowded a population is. Population density is always expressed as the number of individuals per unit of area or volume. For example, the population density of humans in the United States is about 30 people per square kilometer. Table 20-1 shows the population densities for several countries. These estimates are calculated for the total land area. Some areas of a country may be sparsely populated, while other areas are very densely populated.

TABLE 20-1
Population Densities

Country	Population density (individuals/ km^2)
Japan	330
United Kingdom	240
Kenya	50
Mexico	50
United States	30
Russia	10

Dispersion

A third population property is dispersion. **Dispersion** (di-SPUHR-zhuhn) is the spatial distribution of individuals within the population. In a clumped distribution, individuals are clustered together. In an even distribution, individuals are separated by a fairly consistent distance. In a random distribution, each individual's location is independent of the locations of other individuals in the population. The three possible patterns of dispersion are illustrated in Figure 20-2a. Clumped distributions often occur when resources such as food or living space are clumped. Clumped distributions may also occur because of a species' social behavior, such as when zebras gather into herds or birds form flocks. Even distributions usually result from social interactions, but the interactions result in individuals getting as far away from each other as possible. For example, each gannet, which are the birds shown in Figure 20-2c, stakes out a small area on the coast and defends it from other gannets. Each gannet tries to maximize its distance from all of its neighbors, resulting in an even distribution of individuals. A random distribution usually results from seed dispersal by the wind or by birds, as in the third illustration in Figure 20-2a. Forests or a field of wildflowers result from random seed dispersal.

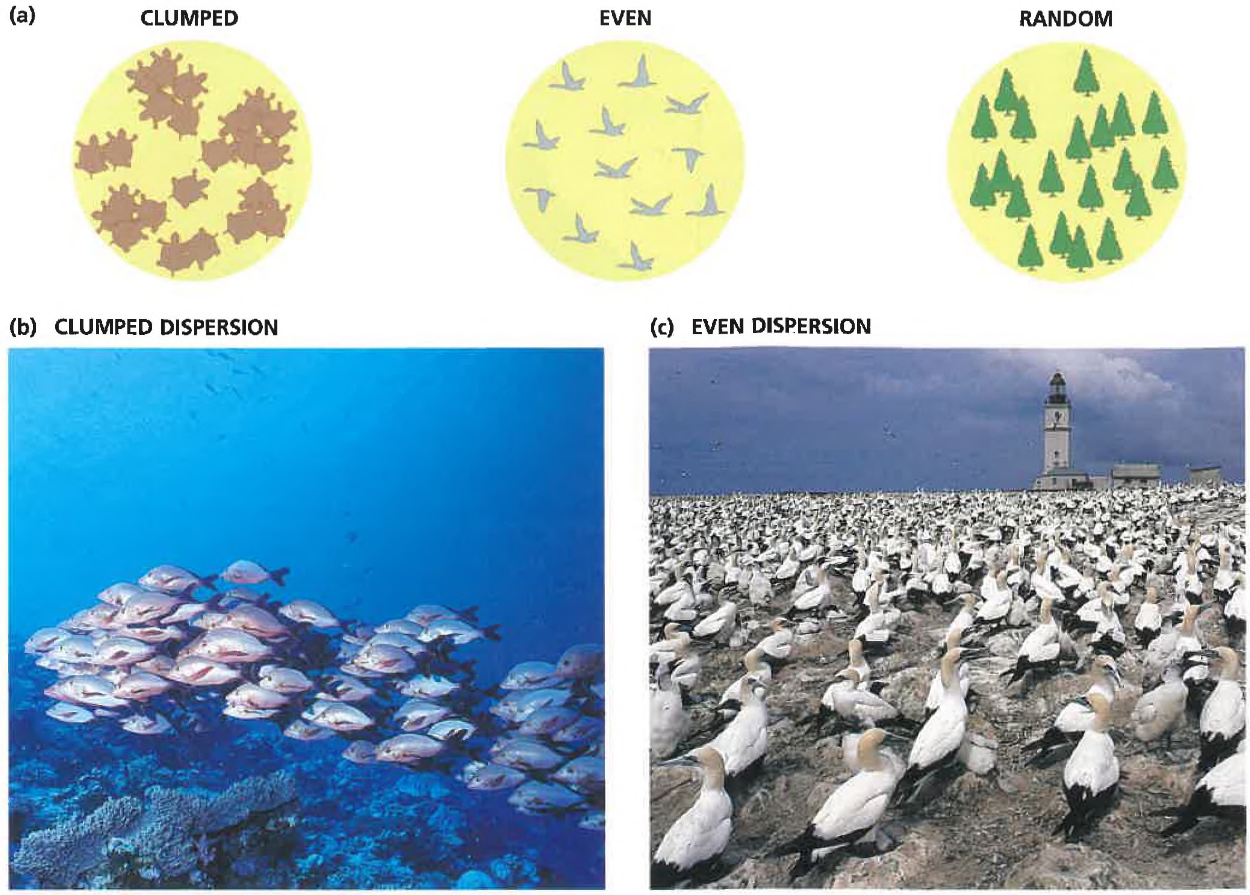


FIGURE 20-2
Illustrated in (a) are the three dispersion patterns—clumped, even, and random. Turtles commonly clump together to bask in the sun. Birds often are observed in even dispersions as a result of social interactions. A forest is an example of random dispersion. Close up, the fishes in (b) may appear to be in an even distribution, but further away, they can be seen to be clumped. The birds in (c) are evenly distributed, but at a great distance they appear to be clumped.

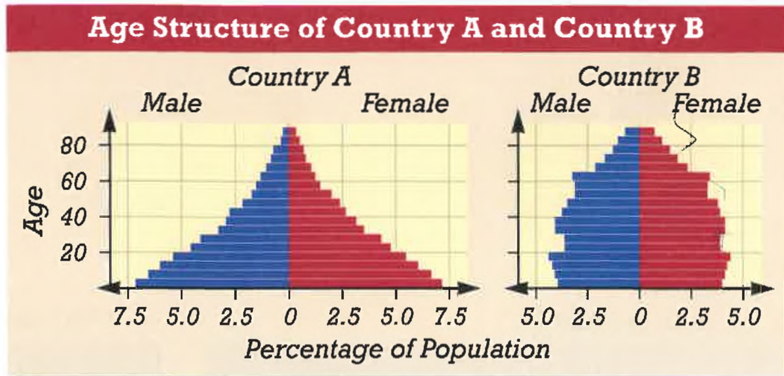
The dispersion pattern of a population sometimes depends on the scale at which the population is observed. The gannets shown in Figure 20-2c are evenly distributed on a scale of a few meters. If the scale of observation is the entire island on which the gannets live, however, the distribution appears clumped because the birds live only near the shore.

POPULATION DYNAMICS

All populations are dynamic—they change in size and composition over time. To understand these changes, more knowledge is needed about the population than its size, density, and dispersion. One important measure is the **birth rate,** the number of births occurring in a period of time. In the United States, for example, there are about 4 million births per year. A second important measure is the **death rate,** or **mortality rate,** which is the number of deaths in a period of time. The death rate for the United States is about 2.4 million deaths per year. Another important statistic is **life expectancy,** or how long on average an individual is expected to live. In the United States in 1996, the life expectancy for a man was 72 years, and for a woman it was 79 years.

FIGURE 20-3

These two diagrams show the age structure by gender of two countries. A comparison indicates that Country A has a higher percentage of young people and a lower percentage of elderly people than Country B does.

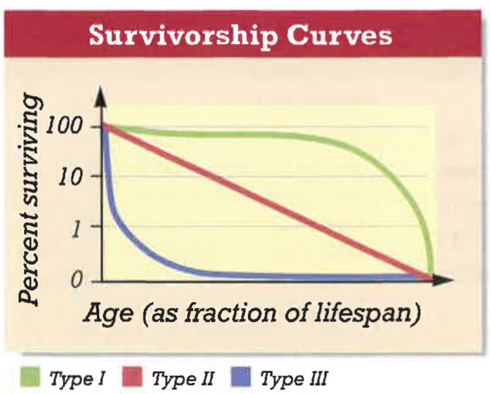


Age Structure

The distribution of individuals among different ages in a population is called **age structure.** Age structures are often presented in graphs, as in Figure 20-3. Many important population processes vary with age. In many species, including humans, very old individuals do not reproduce. Populations with a high percentage of young individuals have a greater potential for rapid growth.

FIGURE 20-4

Humans have a Type I survivorship curve. Some species of birds have a Type II survivorship curve. Some species of fish are examples of a Type III survivorship.



Patterns of Mortality

The mortality rate data of different species tend to conform to one of three curves on a graph, as shown in Figure 20-4. These curves are called **survivorship curves** because they show the likelihood of survival at different ages throughout the lifetime of the organism. In humans or elephants, for instance, the likelihood of dying is small until late in life, when mortality increases rapidly. This pattern of mortality produces the Type I survivorship curve. For other organisms, such as some species of birds, the probability of dying does not change throughout life, giving a linear, or Type II, survivorship curve. Many organisms are very likely to die when young. If an individual survives this early period, however, it has a good chance of surviving to old age. This type of survivorship curve, called Type III, is characteristic of animals such as oysters, salmon, and many insects.

SECTION 20-1 REVIEW

1. Explain how two populations can be the same size but have different densities.
2. Explain why even distributions usually result from social interactions between individuals.
3. Explain how it is possible to conclude from Figure 20-3 that the life expectancy of individuals in Country B is greater than that of individuals in Country A.
4. How does Figure 20-3 indicate which country's population has the greatest potential for rapid growth?
5. Explain why natural selection might favor a high reproduction rate in organisms with Type III survivorship curves.
6. CRITICAL THINKING Explain two difficulties an ecologist might have in counting a population of migratory birds. Develop and explain a method for estimating the size of such a population.

MEASURING POPULATIONS

SECTION

20-2

OBJECTIVES

▲ Describe the exponential model of population growth.

● Compare the similarities and differences between the logistic model and the exponential model.

■ Distinguish between density-dependent and density-independent regulatory factors.

◆ List three reasons why small populations are more vulnerable to extinction.

Charles Darwin calculated that a single pair of elephants could increase to a population of 19 million individuals within 750 years. The fact that the world is not overrun with elephants is evidence that some factor or factors restrain the population growth of elephants. In this section you will study how populations grow and what factors limit their growth.

POPULATION GROWTH RATE

Demographers, scientists who study population dynamics, define the **growth rate** of a population as the amount by which a population's size changes in a given time.

Whether a population grows, shrinks, or remains the same size depends on four processes: birth, death, emigration, and immigration. **Immigration** (im-uh-GRAY-shuhn) is the movement of individuals into a population, and **emigration** (em-i-GRAY-shuhn) is the movement of individuals out of the population. Two of these processes—birth and immigration—add individuals to a population, while the other two processes—death and emigration—subtract individuals from the population. For simplicity's sake, demographers usually assume that immigration and emigration are zero when calculating a population's growth rate. By making this simple assumption, a population's growth rate can be described mathematically and can be graphed.

It is customary for demographers to divide large populations into groups of 1,000 and to present data per capita, meaning per individual. Birth rates, death rates, and growth rates for a large population are usually expressed per capita. For example, if there are 52 births and 14 deaths per 1,000 individuals in a large population in one year, the per capita birth rate would be $^{52}/_{1,000}$, or 0.052 births per individual per year. The per capita death rate would be $^{14}/_{1,000}$, or 0.014 deaths per individual per year. The per capita growth rate can be found by the following simple equation:

$$\text{birth rate} - \text{death rate} = \text{growth rate}$$

internetconnect

SCILINKS NSTA

TOPIC: Factors affecting population growth
GO TO: www.scilinks.org
KEYWORD: HM383

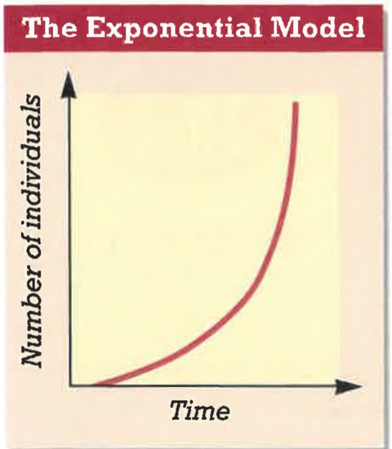


FIGURE 20-5

The graph of exponential population growth has a characteristic J shape. The exponential model indicates infinite, constantly increasing population growth.

Using the same example, we can calculate the per capita growth rate as follows:

$$0.052 \text{ (births per capita)} - 0.014 \text{ (deaths per capita)} = 0.038 \text{ (growth per capita)}$$

To find the number of new individuals that will be added to the population in a year, simply multiply the per capita growth rate by the number of individuals in the population. If the population in our example numbers 50,000, the population will increase by 1,900 individuals in one year.

$$0.038 \times 50{,}000 = 1{,}900$$

If the growth rate is a positive number, the population is increasing. If it is a negative number, the population is shrinking.

THE EXPONENTIAL MODEL

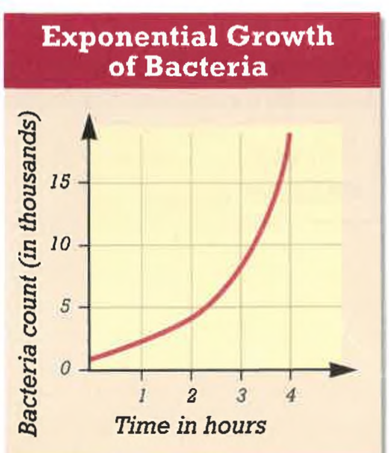
The **exponential** (EKS-poh-NEN-shuhl) **model** of population growth describes a population that increases rapidly after only a few generations; the larger the population gets, the faster it grows. This is called **exponential growth.** In constructing an exponential model of population growth, it is assumed that birth rates and death rates remain constant, however large the population becomes.

Predictions Based on the Exponential Model

One way to understand predictions based on the exponential model is to look at a graph of population size over time. Population growth, according to the exponential model, follows the characteristic J-shaped curve shown in Figure 20-5. As you can see on the graph, the population grows slowly when it is small, but its growth speeds up as more and more individuals are added to the population. We can predict that the population will grow indefinitely and at an increasingly rapid rate based on the exponential model. Figure 20-6 shows the exponential growth of bacteria in a laboratory culture.

FIGURE 20-6

The population increase of bacteria in the laboratory produces a characteristic graph of exponential growth. With this kind of graph, the size of the population of bacteria at any future time can be predicted if the culture is provided with unlimited resources, such as food.



Limitations of the Exponential Model

The ultimate test of an exponential model is how well it matches the growth pattern of a real population. Do populations grow exponentially? The answer is yes, but only under rare conditions and for short periods of time. For example, populations of bacteria and other microorganisms can grow exponentially in the laboratory

Data Table

Time	0	1	2	3	4
Bacteria count	1,000	2,000	4,000	8,000	16,000

if they are provided with an abundance of food and space and if their waste is removed.

In reality, populations cannot grow indefinitely because the resources they depend on become scarce and wastes accumulate. All populations are limited by their environment. A factor that restrains the growth of a population is called a **limiting factor.**

As a population grows, competition among individuals for the shrinking supply of resources intensifies, and each individual, on average, obtains a smaller share. This reduces each individual's ability to fight off disease, to grow, and to reproduce. The results for the population are a declining birth rate and an increasing mortality rate. Figure 20-7 shows how increasing population size affected the growth of a species of plant.

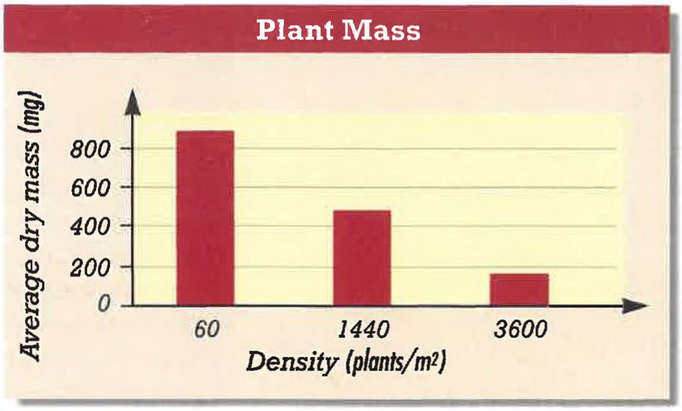


FIGURE 20-7

The graph displays the results of an experiment that tests how the growth of a plant is affected under three conditions of crowding. Under the condition of least crowding, the plants were observed to grow larger.

THE LOGISTIC MODEL

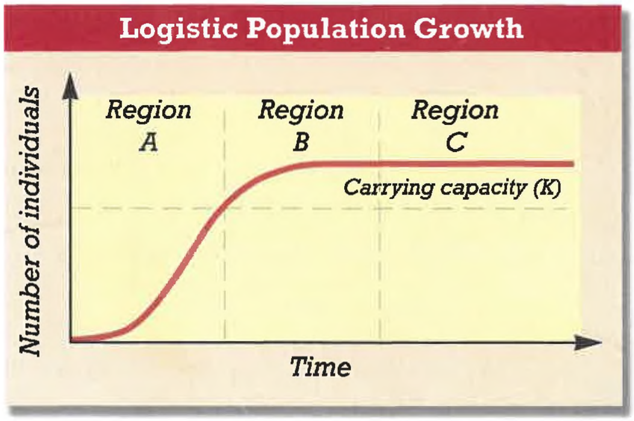
The **logistic** (loh-JIS-tik) **model** of population growth builds on the exponential model but accounts for the influence of limiting factors. Birth rates and death rates are not constant, but vary with population size: birth rates decline and death rates rise as the population grows. The logistic model includes a new term, **carrying capacity** (symbolized by K), the number of individuals the environment can support over a long period of time.

A graph of logistic growth looks like a stretched-out letter *S.* Examine Figure 20-8. When the population size is small, birth rates are high and death rates are low, and the population grows at very near the exponential rate, as shown in region *A.* As the population size approaches the carrying capacity, however, the population growth rate falls due to the falling birth rate and the increasing death rate, as shown in region *B.* When a population size is at its carrying capacity, the birth rate equals the death rate and growth stops, as shown in region *C.* This type of growth is known as **logistic growth.**

The logistic model, like the exponential model, contains some assumptions. One such assumption is that the carrying capacity is constant and does not fluctuate with environmental changes. In reality, carrying capacity does fluctuate. It is greater when prey is abundant, for instance, and smaller when prey is scarce. The logistic and exponential models are not accurate representations of real populations, but they are an important tool that scientists use to study population growth and regulation.

FIGURE 20-8

The graph of logistic population growth describes a population stabilizing around *K*, the carrying capacity. The logistic graph is similar to the exponential graph in region A. In region B, the graph begins to indicate a slowing rate of increase. In region C, the graph indicates that the population has become stable, neither growing nor getting smaller.



POPULATION REGULATION

Two kinds of limiting factors, which control population size, have been identified. **Density-independent factors,** such as weather, floods, and fires, reduce the population by the same proportion, regardless of the population's size. For example, if a forest fire destroys a population of chipmunks, it does not matter if the population of chipmunks is 1 or 100. An unseasonable cold snap is a density-independent factor because its severity and duration are completely independent of population size. **Density-dependent factors** include resource limitations, such as shortages of food or nesting sites, and are triggered by increasing population density.

Population Fluctuations

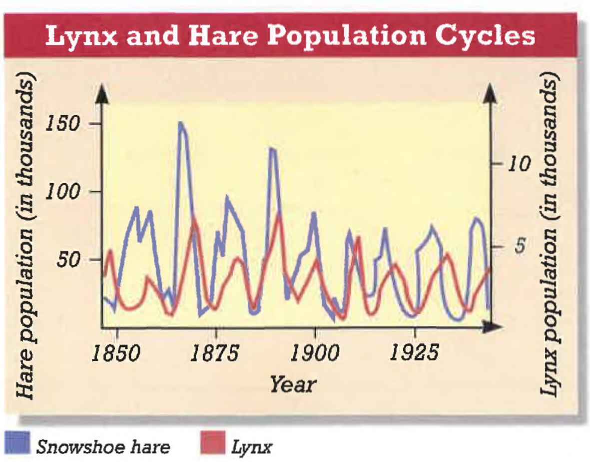
All populations fluctuate in size. Some population fluctuations are clearly linked to environmental changes. For example, a drought may reduce a population of deer living in a forest. Some population fluctuations are not obviously connected to environmental fluctuations, and explaining their occurrence is much more difficult. The famous population cycles of the snowshoe hare, first described by Charles Elton, one of the pioneers of ecology, is shown in Figure 20-9. Elton obtained more than 70 years of records showing the number of snowshoe hare pelts the Hudson's Bay Company of Canada purchased from trappers. He assumed that the number of pelts purchased in a year indicated the size of the snowshoe hare population. The records showed that the hare population underwent a very regular cycle, with about 10 years between peaks in population size. When Elton examined the records for the number of lynx pelts purchased, he found that the lynx, a medium-sized species of cat that preys on snowshoe hares, also followed a population cycle. The peaks in the lynx population usually occurred one or two years after peaks in the hare population.

Elton thought that each species was the cause of the other's cycle. Thus, when the population of snowshoe hares increased, providing more food for the lynxes, the lynx population also increased. The increased lynx population then ate more hares, so the hare population decreased. With less food, more lynxes starved and the lynx population declined, allowing the hare population to increase and start the cycle over again. However, the observation that the same cycles occur in snowshoe hare populations living on islands without lynxes indicates that this explanation is inaccurate. Another possible explanation is that the lynx cycle is dependent on the hare population but the hare cycle is dependent on some other factor.

FIGURE 20-9

The hare and the lynx (a) were observed by Elton to have parallel changes in their population cycles. The graph below (b) shows the data recorded by Elton supporting his idea that each animal controlled the other animal's cycle. You can see that the cycles fluctuate together. Because hares show the same population cycles when there are no lynxes present, it is now known that lynxes are not controlling factors in the hares' cycles.

(a)



(b)

Perils of Small Populations

The rapidly growing human population has caused extreme reductions in the populations of some other species and subspecies. For instance, fewer than 200 Siberian tigers remain in the wild due to overhunting and habitat destruction. Even greater reductions have been experienced by the California condor, which was once found throughout the southwestern United States. By the 1980s, the condor's wild population was down to nine individuals.

Small populations, such as the cheetahs shown in Figure 20-10, are particularly vulnerable to extinction. Environmental disturbances, such as storms, fires, floods, or disease outbreaks, can kill off the entire population or leave too few individuals to maintain the population. Also, the members of a small population may be descended from only a few individuals, increasing the likelihood of **inbreeding,** or mating with relatives. Offspring of related parents often have fewer offspring, are more susceptible to diseases, and have a shorter life span. Inbreeding in small populations often leads to decreased genetic variability, and, over evolutionary time, may reduce the population's ability to adapt to changing environmental conditions.

FIGURE 20-10

Biologists estimate that there are fewer than 15,000 cheetahs remaining in the wild. Inbreeding in small populations, such as the one shown, leads to a loss of genetic diversity or variability. Cheetahs are bred in captivity in an effort to maintain their remaining genetic variability. Some of these cheetahs may eventually be released into the wild.

SECTION 20-2 REVIEW

1. **Explain what is described by the exponential model.**
2. **According to the exponential model, how do birth and death rates change with population size?**
3. **Describe two differences between the exponential model and the logistic model.**
4. **List two density-independent factors.**
5. **Explain how inbreeding can threaten the survival of a small population.**
6. **CRITICAL THINKING Write a brief paragraph supporting the assumption that immigration and emigration are insignificant factors when studying global human population growth.**

SECTION

20-3

OBJECTIVES

▲ Explain how the development of agriculture changed the pattern of human population growth.

● Describe the change in human population growth that began around 1650.

■ Describe how growth rates have changed since World War II.

◆ Compare the general standard of living in developed countries with that in developing countries.

internetconnect

SCILINKS NSTA

TOPIC: History of population growth
GO TO: www.scilinks.org
KEYWORD: HM388

HUMAN POPULATION GROWTH

In the time it takes you to read this chapter, the human population will grow by about 10,000 people. The rapid growth of the human population over the last several centuries is unprecedented in history. What caused this rapid growth? How long can it continue? This section examines these and other questions about the human population explosion.

HISTORY OF HUMAN POPULATION GROWTH

From the origin of *Homo sapiens*, more than 500,000 years ago, until about 10,000–12,000 years ago, the human population grew very slowly. During this time, humans lived in small nomadic groups and obtained food by hunting animals and gathering roots, berries, nuts, shellfish, and fruits. This way of life is called the **hunter-gatherer lifestyle.** By studying the few hunter-gatherer societies that exist today, scientists have learned that the low rate of population growth results from small populations and high mortality rates, especially among infants and young children, who never reach reproductive maturity.

The Development of Agriculture

The hunter-gatherer lifestyle began to change about 10,000 to 12,000 years ago, when humans discovered how to domesticate animals and cultivate certain plants for food. This dramatic change in lifestyle is called the **agricultural revolution,** and it led to profound changes in every aspect of life. Most important, agriculture greatly stabilized and increased the available food supply. As a result, the human population began to grow faster. About 10,000 years ago, there were between 2 million and 20 million people on Earth. By about 2,000 years ago, the population had increased to between 170 million and 330 million.

The Population Explosion

As you can see in Figure 20-11, human population growth continued through the Middle Ages, despite some short-term reversals. The outbreak of bubonic plague in 1347–1352 is thought to have killed about 25 percent of the population of Europe. Human population growth began to accelerate after 1650, primarily because of a sharp decline in death rates. There are many reasons for the decline in death rates, including better sanitation and hygiene, control of disease, increased availability of food, and improved economic conditions. While death rates fell, birth rates remained high, resulting in rapid population growth. The human population was about 500 million in 1650 and had risen to about 1 billion by 1800 and 2 billion by 1930.

Mortality rates fell sharply again in the decades immediately following World War II because of improvements in health and hygiene in the world's poorer countries. Birth rates in these countries remained high, pushing the per capita growth rate to its highest values. It took most of human history for the human population to reach 1 billion, but the population grew from 3 billion to 5 billion in just the 27 years between 1960 and 1987.

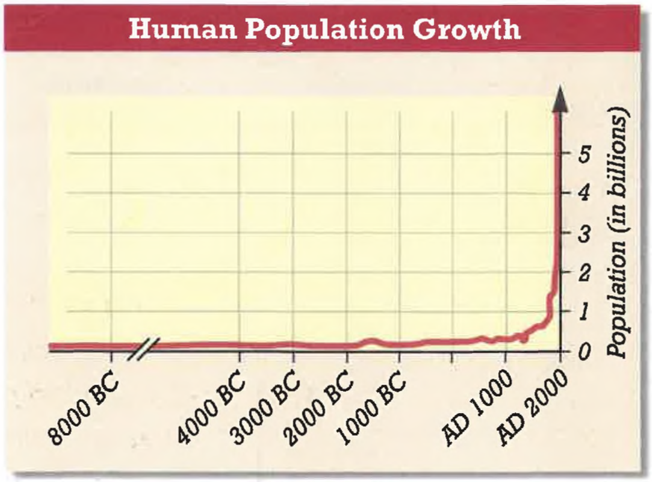


FIGURE 20-11

The J shape of the graph is characteristic of exponential growth. Many ecologists agree that the current human population growth rate is not sustainable.

Population Growth Today

The global growth rate peaked in the late 1960s at about 0.021 per capita. Because birth rates have decreased in many countries, the growth rate has gradually declined slowly to its current level of about 0.014 per capita. This decline has led some people to mistakenly conclude that the population is not increasing. In fact, the number of people that will be added to the world population this year is larger than it was when the growth rate was at its peak. This is simply a function of today's greater population size. For example, in 1970 there were about 3.7 billion people, and the growth rate was about 0.0196. In 1970, therefore, about $3,700,000,000 \times 0.0196$, or about 73 million people, were added to the world's population. In 1999 there were 6 billion people and the growth rate was 0.014 per capita, so the number of people added to the population was $6,000,000,000 \times 0.014$, or 84 million.

Today about 20 percent of the world's population live in **developed countries.** This category includes all of the world's modern, industrialized countries, such as the United States, Japan, Germany, France, the United Kingdom, Australia, Canada, and Russia. On average, people in developed countries are better educated, healthier, and live longer than the rest of the world's population. Population growth rates in developed countries are very low —less than 0.01 per capita. The populations of some of these countries, such as Russia, Germany, and Hungary, are shrinking because death rates exceed birth rates.

Most people (about 80 percent of the world's population) live in **developing countries,** a category that includes most countries in Asia and all of the countries in Central America, South America, and Africa. In general, these countries are poorer than the more-

Quick Lab

Demonstrating Population Doubling

Materials pencil, paper, sheet of newspaper

Procedure

1. Make a data table. Label the columns "Fold number," "Number of layers," and "Power of 2." Write the numbers 1-10 in the first column.
2. Fold a sheet of newspaper repeatedly in half, as your teacher demonstrates. Fill in your data table after each fold.

Analysis What can you conclude about the speed at which populations grow by doubling?

TABLE 20-2 ***Population Statistics for Selected Countries***

Country	Population (millions)	Growth rate (per capita)	Projected population in 2025 (millions)	Estimated doubling time (years)
China	1,200	0.011	1,500	64
India	950	0.019	1,400	37
United States	265	0.006	335	117
Brazil	161	0.017	202	41
Russia	148	−0.005	153*	N/A
Japan	126	0.002	126	350
Nigeria	104	0.031	246	23
Mexico	95	0.022	142	32
Germany	82	−0.001	79*	N/A
United Kingdom	59	0.002	63	350
France	58	0.003	64	233
South Africa	45	0.023	70	30
Kenya	28.2	0.027	49	26
Australia	18	0.008	23	88
Haiti	7.3	0.023	11	30

* projection assumes per capita growth rate will increase to a positive value
N/A = Not applicable

developed countries, and their populations are growing much faster—at a growth rate of more than 0.02 per capita. Table 20-2 shows some population statistics for several countries.

The human population explosion will eventually stop. The only questions still to be answered are How large will the population be? and Will the planet be able to support the population over the long term? The answers to both questions depend on whether we use our resources wisely so that the future productivity of Earth's ecosystems is not compromised.

SECTION 20-3 REVIEW

1. **What effect did the agricultural revolution have on the growth of the human population?**
2. **Explain why mortality rates began to decline rapidly around 1650.**
3. **Why did population growth rates increase rapidly after World War II?**
4. **How do population growth rates in the developing countries compare with those of the developed countries?**
5. **How do living standards in the developing countries compare with those in the developed countries?**
6. **CRITICAL THINKING In five or six sentences, differentiate between growth rate and birth rate, and evaluate the statement that a decreasing birth rate may lead to a decreasing growth rate.**

CHAPTER 20 REVIEW

SUMMARY/VOCABULARY

20-1

- A population is a group of individuals of the same species living in the same place in the same time period.
- A population's size is the number of individuals it contains. Population density is a measure of how crowded the population is. The dispersion pattern—random, even, or clumped—indicates the distribution of individuals within the population.
- A population's age structure indicates the percentage of individuals at each age.
- Populations show three patterns of mortality: Type I (low mortality until late in life), Type II (constant mortality throughout life), and Type III (devastating mortality early in life followed by low mortality for the remainder of the life span).

Vocabulary

age structure (382)
birth rate (381)
death/mortality rate (381)
dispersion (380)
life expectancy (381)
population density (380)
survivorship curve (382)

20-2

- Four processes determine whether a population will shrink or grow: birth, death, immigration, and emigration.
- The exponential model describes perpetual growth at an increasing rate in a population. The model assumes constant birth and death rates and no immigration or emigration.
- In the logistic model, birth rates fall and death rates climb as the population grows.
- The carrying capacity is the number of individuals the environment can support for an indefinite period of time. At the carrying capacity, birth and death rates are equal, and the population size is stable.
- Density-independent factors kill the same percentage of a population regardless of its size. Density-dependent factors kill more individuals in large populations than in small ones.
- Populations fluctuate over time due to environmental changes.
- Small populations are less able to rebound from environmental changes, they are more likely to experience inbreeding, and their genetic diversity is often low.

Vocabulary

carrying capacity (385)
density-dependent factor (386)
density-independent factor (386)
emigration (383)
exponential growth (384)
exponential model (384)
growth rate (383)
immigration (383)
inbreeding (387)
limiting factor (385)
logistic growth (385)
logistic model (385)

20-3

- About 10,000–12,000 years ago, human population growth was slow.
- The development of agriculture increased the growth rate of the population. Improvements in hygiene, diet, and economic conditions around 1650 further accelerated population growth.
- The population grew at its fastest rate in the decades immediately after World War II, largely because of better sanitation and medical care in the poorer countries.
- Today, population growth is faster in the less-developed countries and slower in the more-developed countries.

Vocabulary

agricultural revolution (388)
developed countries (389)
developing countries (389)
hunter-gatherer lifestyle (388)

REVIEW

Vocabulary

Explain the difference between the terms in each of the following pairs:

1. density-dependent factor, density-independent factor
2. density, dispersion
3. exponential growth, logistic growth
4. carrying capacity, density
5. developing countries, developed countries

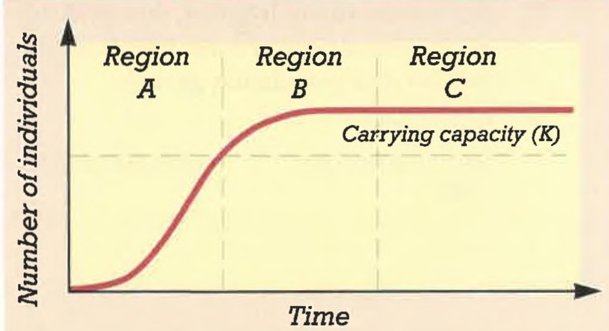
Multiple Choice

6. A clumped distribution (a) occurs when individuals are evenly spaced (b) may occur when resources are concentrated (c) occurs only because of social interactions between individuals (d) occurs only among plants.
7. Life expectancy (a) refers to the maximum life span of an individual (b) is the average life span (c) depends only on birth rates (d) is the same for all species.
8. Population growth (a) is a group of individuals of the same species living in the same place (b) is the spatial distribution of organisms in a population (c) is the change in the number of individuals in a population over a period of time (d) occurs only if all individuals in the population survive and reproduce.
9. In the exponential model, the growth rate (a) is the same as the birth rate (b) is the change in population size after birth and death rates have been accounted for (c) changes with population size (d) is zero at the carrying capacity.
10. According to the exponential model, (a) population growth stops at the carrying capacity (b) population growth increases and then decreases (c) the immigration rate falls with increasing population size (d) population growth continues indefinitely.
11. Which of the following is not true of the carrying capacity in the logistic model? (a) varies with population size (b) remains constant (c) represents the maximum sustainable population (d) is the population size at which the birth rate equals the death rate.
12. Which of the following is not a density-independent factor for a population of deer in a forest? (a) a period of freezing weather (b) the number of cougars in the forest (c) a drought (d) a landslide
13. Inbreeding can be harmful to a population because it (a) increases the genetic variability of the population (b) increases the rate of evolution in the population (c) can increase mortality rate of offspring (d) decreases the carrying capacity.
14. During the hunter-gatherer period of human history, (a) death rates were high (b) crops were cultivated to provide food (c) the population grew to 1 billion individuals (d) population growth rates were high.
15. The cause of the decline in death rates following World War II was (a) introduction of genetically engineered crops (b) a decrease in life expectancy (c) improved hygiene and medical care (d) declining birth rates.

Short Answer

16. A scientist observes that the population of turtles in a pond shows a clumped distribution. Explain two reasons why turtles might show this kind of distribution.
17. Describe how an even distribution differs from a random distribution. Draw an example of each type of distribution.
18. What is a survivorship curve? What are the three types of survivorship curves? Name an organism that shows each kind of curve.
19. Explain one key assumption of the exponential model of population growth. What does the model help scientists predict about changes in population size over time?
20. Explain three reasons why small populations are particularly vulnerable to extinction.
21. Examine the graph below. Explain how the logistic model describes population changes in region A, region B, and region C.

Logistic Population Growth



22. What was the agricultural revolution? What effect did it have on population growth? Before the agricultural revolution occurred, how did people obtain food?

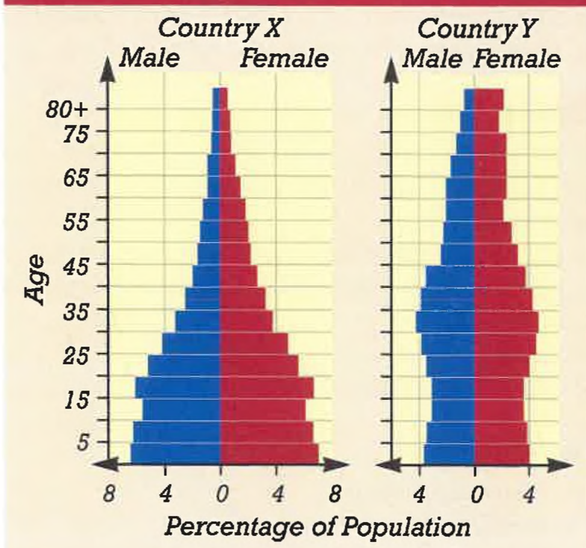
23. The human population began to grow very rapidly about 1650. Describe three factors that caused this change in the rate of population growth.

24. **Unit 7–Ecosystem Dynamics** Write a report summarizing how the availability of resources on a ranch determine the carrying capacity of the ranch. What are the risks of maintaining a population of livestock that exceeds the carrying capacity of the ranch?

CRITICAL THINKING

1. Because we humans have more power to alter our environment than other animals do, we can affect the carrying capacity of our environment. How do we increase or decrease the carrying capacity of our local area?
2. The cause of the population cycle of the snowshoe hare is still a mystery. Suggest two possible explanations for why this cycle occurs. Describe how you would test each possibility.
3. Explain how disease could be a density-dependent factor in a population.
4. Describe an imaginary population, and name at least two density-dependent factors that affect the population when it has reached carrying capacity. Draw a graph of what you think logistic population growth would look like for the population. Include the effects that a density-independent event might have on the graph.
5. The population of country X is projected to grow rapidly in the next few decades, while slow growth is projected for country Y. Using only the age structures in the figure below, explain why these projections are plausible.

Age Structure of Country X and Country Y



EXTENSION

1. Read "Japan's Harsh Reality Check" in *Newsweek,* January 10, 2000, on page 57. According to the article, how does Japan's aging society and low birthrate influence how Japan will rank as a world power in the twenty-first century? Why is the slowed birthrate in Japan unlikely to change?
2. Using library resources or an on-line database, obtain information about how the United States population census is conducted. Examine the results of the 1990 census, and answer these questions. What was the population of the United States in 1990? How much larger was the 1990 population than the 1980 population? Which state grew by the greatest percentage? Which states showed reductions in population?
3. Obtain population records for your town, city, or county. Try to get data that cover as long a period of time as possible. Make a graph that shows changes in population size. Describe any patterns you see in the data.

Studying a Yeast Population

OBJECTIVES

- Observe the growth and decline in a population of yeast cells.
- Apply the underlying principles to changes in human populations.

PROCESS SKILLS

- calculating
- measuring
- collecting data
- organizing data
- analyzing data

MATERIALS

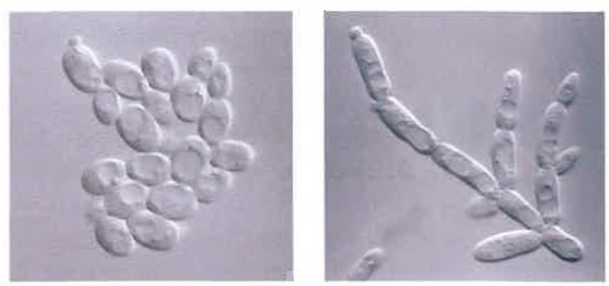
- yeast culture
- 1 mL pipet
- test tube
- iodine in dropper bottle
- microscope slide ruled in 2 mm squares
- safety goggles
- coverslip
- compound microscope

Background

1. What is a population?
2. List three properties of populations.
3. What is carrying capacity?
4. What are some common limiting factors that prevent populations from exceeding their carrying capacity?
5. How can populations be sampled to achieve an accurate count?

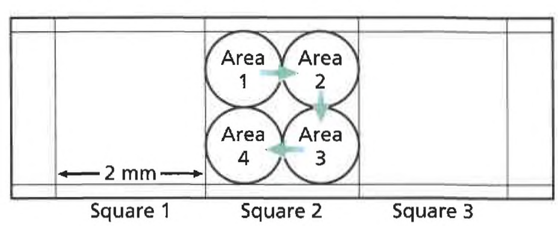
PART A Day 1

1. CAUTION **Put on a lab apron, goggles, and disposable gloves.**
2. Your teacher will transfer approximately 1 mL of the yeast culture to a test tube and then add 2 drops of iodine to the test tube. CAUTION **Work with care—iodine is a poison and an eye irritant. If you get iodine on your skin or clothing, wash it off at the sink while calling to your teacher. If you get iodine in your eyes, immediately flush your eyes with water at the eyewash station while calling to your teacher.**
3. Use the 1 mL pipet to transfer 0.1 mL (one drop) from the test tube to a ruled microscope slide. Carefully lower a coverslip over the drop. CAUTION **Slides break easily. Use caution when handling them.**
4. Using the compound light microscope, view your slide under low power. Perform the following steps to estimate the total number of yeast cells in 0.1 mL. Note the appearance of your yeast culture. Your culture should look similar to the one shown in the photograph labeled (a) below.



(a) (b)

5. Each slide is ruled in 2 mm squares. The figure below shows only 3 of these 2 mm squares. You will be counting the cells in six 2 mm squares. Focus on the yeast cells and notice the black grid lines on the slide. Switch to the 400× objective, and align the slide so that you can just see the top left corner of one 2 mm square, area 1, shown in the figure below.



6. Count all the yeast cells in area 1, and record the number in a data table similar to the one on the facing page.

ESTIMATED NUMBER OF YEAST CELLS IN 0.1 mL OF CULTURE

Time (hours)	Number of cells per 2 mm square						Average	Population size (cells/0.1 mL)
	1	2	3	4	5	6		
0								
24								
48								
72								
96								

7. Move the slide to area 2. Continue counting cells and recording data in your lab report until you have counted the cells in each of the four areas that make up one 2 mm square. Add the total number of cells in the square, and record this number in your lab report.
8. Switch the microscope to low power, and move the slide one square to the left. Under high power, count the cells and record the number in your lab report.
9. Repeat steps 5–8 until you have counted the cells in a total of six squares. Add the total number of cells you counted in the six squares. Calculate the average number of yeast cells in a 2 mm square by dividing the total by 6. Record this number in your data table under "Average."
10. Clean up your materials and wash your hands before leaving the lab.

PART B Days 2–5

11. Repeat steps 1–10 each day for four more days. Record your data for 24, 48, 72, and 96 hours. Note any changes in the appearance of your yeast culture in your lab report. If possible, repeat steps 1–10 again after the weekend. The yeast culture may have changed in appearance to resemble the photograph labeled (b) on the facing page.
12. To find the total population of yeast cells in 1 mL of yeast culture (the amount in the test tube), multiply the average number of cells counted in a 2 mm square by 2,500.
13. Graph your data using the values you calculated for the entire test-tube population over the five-day period.
14. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. What effect does iodine have on yeast cells?
2. Why were several areas counted and then averaged each day?
3. When was the most rapid growth? the slowest growth?
4. When was the growth peak reached?
5. How did the yeast population change over time?
6. What limiting factors probably caused the yeast population to decline?
7. If you kept counting for several more days, what do you think would happen to the yeast population?
8. What limiting factors that affect yeast also affect human populations?
9. Did the growth rate of the yeast population more closely follow the predictions of the exponential model or the logistic model? Defend your answer.
10. In what ways do population growth and decline in a yeast population resemble growth and decline in a human population? In what ways do they differ?
11. To find the total number of cells in 1 mL, you multiplied the number of cells you counted in a 2 mm square by 2,500. To see why this works, calculate the volume of fluid in one of the small squares. The fluid forms a layer about 0.1 mm thick on the microscope slide. So the volume is 2 mm $\times$ 2 mm $\times$ 0.1 mm = 0.4 mm^3. Now convert to milliliters, remembering that 1 mL = 1 cm^3 and 1 cm^3 = 1,000 mm^3. Finally, divide your answer into 1 mL to find what multiplier you need to use to go from the number of cells per square to the number of cells per milliliter.

Further Inquiry

Is it possible to set up a population of yeast that continues to grow for a week without declining? Would it be possible to keep the population size growing indefinitely?

CHAPTER 21

COMMUNITY ECOLOGY

This coral-reef community rivals a tropical rain forest in number of species.

FOCUS CONCEPT: ***Interdependence of Organisms***

As you read, note how evolution shapes the interactions among species in a community.

BIOLOGY INTERACTIVE TUTOR

Unit 7—*Ecosystem Dynamics*
Units 1–6

SECTION

21-1

SPECIES INTERACTIONS

Just as populations contain interacting members of a single species, communities contain interacting populations of many species. This chapter introduces the five major types of close interactions, or ***symbioses,*** *among species—predation, parasitism, competition, mutualism, and commensalism. These symbiotic relationships help determine the nature of communities.*

OBJECTIVES

▲ Distinguish predation from parasitism.

● Evaluate the importance of mimicry as a defense mechanism.

■ Describe two ways plants defend themselves against herbivores.

◆ Explain how competition can affect community structure.

▲ Contrast mutualism with commensalism, and give one example of each type of relationship.

PREDATION

Predation is a powerful force in a community. In predation, one individual, the **predator,** captures, kills, and consumes another individual, the **prey.** Predation influences where and how species live by determining the relationships in the food web. Predation is also an effective regulator of population size.

Predators, Prey, and Natural Selection

Natural selection, the major mechanism of evolution, favors adaptations that improve the efficiency of predators at finding, capturing, and consuming prey. For example, rattlesnakes have adaptations for locating their prey with an acute sense of smell and with specialized heat-sensitive pits located below each nostril, as shown in Figure 21-1. These pits enable a rattlesnake to aim its strike at warm-bodied prey with great accuracy, even in the dark. Other predator adaptations include the webs of spiders; the sharp, flesh-cutting teeth of wolves and coyotes; and the striped pattern of a tiger's coat, which provides camouflage in the tiger's grassland habitat.

FIGURE 21-1

A rattlesnake is able to detect a variation in temperature of as little as 0.1°C, which helps it locate prey. To disable its prey, the snake injects a strong, fast-acting poison through sharp, hollow fangs.

(a) (b)

FIGURE 21-2

Favorable coloration helps many organisms escape predation. The mantis in (a), *Chaenadodus rhombicollis,* cannot readily be detected among the leaves. The frog in (b), *Dendrobates matrimaculatus,* is brightly colored to warn other organisms that it is extremely poisonous.

A predator's survival depends on its ability to capture food, but a prey's survival depends on its ability to avoid being captured. Therefore, natural selection has favored ways for the prey to avoid, escape, or otherwise ward off predators. Some organisms flee when a predator approaches. Others escape detection by hiding or by resembling an inedible object. Can you find the mantis shown in Figure 21-2a, for example? Some organisms, like the frog shown in Figure 21-2b, are poisonous and use bright colors to warn other organisms of their toxicity.

Mimicry

Deception is important in antipredator defenses. In a defense called **mimicry,** a harmless species resembles a poisonous or distasteful species. The harmless mimic is protected because it is often mistaken to be its dangerous look-alike. The king snake shown in Figure 21-3b is a mimic of the poisonous coral snake shown in Figure 21-3a.

Another form of mimicry is when two or more dangerous or distasteful species look similar. Many kinds of bees and wasps have similar patterns of alternating yellow and black stripes, for example. This kind of mimicry benefits each species involved because a predator that encounters an individual of one species will avoid similar individuals.

Word Roots and Origins

parasite

from the Latin word *parasitus,* meaning "one who eats at the table of another"

Plant-Herbivore Interactions

Animals that eat plants are known as **herbivores.** Ecologists usually classify the relationship between plants and herbivores as a form of predation.

Through natural selection, plants have evolved adaptations that protect them from being eaten. Physical defenses, such as sharp thorns, spines, sticky hairs, and tough leaves, can make the plant more difficult to eat. Plants have also evolved a range of chemical defenses. They synthesize chemicals from products of their metabolism, called **secondary compounds,** that are poisonous, irritating,

(a) Eastern coral snake, *Micrurus fulvius fulvius*

(b) Scarlet king snake, *Lampropeltis triangulum elapsoides*

FIGURE 21-3

The scarlet king snake is easy to differentiate from the coral snake. In the coral snake, the red and yellow rings are together. In the king snake, they are separated by a black ring. Also, the coral snake has a black snout, while the king snake has a red snout.

or bad-tasting. Some examples of secondary compounds that provide a defensive function include strychnine (found in the leaves of plants of the genus *Strychnos*) and nicotine (which is toxic to insects and is found in tobacco leaves). Poison ivy and poison oak produce an irritating chemical that causes a rash on most people. Although secondary compounds are usually toxic, many also have medicinal uses. A large number of drugs, including morphine, atropine, codeine, taxol, and quinine, are derived from the secondary compounds of plants.

PARASITISM

Parasitism is a species interaction that resembles predation in that one individual is harmed while the other individual benefits. In parasitism, one individual, known as the **parasite,** feeds on another individual, known as the **host.** But while most forms of predation immediately remove an individual of the prey species from the population, parasitism usually does not result in the immediate death of the host. Often, the parasite feeds on the host for a long time instead of killing it.

Parasites can be grouped into two general categories, based on how they interact with their host. **Ectoparasites** (EK-toh-PER-uh-siets) are external parasites; they live on their host but do not enter the host's body. Examples of ectoparasites are ticks, fleas, lice, leeches, lampreys, and mosquitoes. **Endoparasites** (EN-doh-PER-uh-siets) are internal parasites, and they live inside the host's body. Familiar endoparasites are disease-causing bacteria, protists such as malaria parasites, and tapeworms.

Evolution of Parasites and Their Hosts

Parasites can have a strong negative impact on their host, affecting both the health and reproduction of the host. Consequently, parasitism has stimulated the evolution of a variety of defenses in hosts. Skin is an important defense that prevents most parasites from entering the body. Openings through which parasites could pass,

Quick Lab

Analyzing Predation

Materials 4.1 m white string, 4 stakes, 40 colored toothpicks, stopwatch or kitchen timer, meterstick

Procedure

1. Mark off a 1 m square in a grassy area using the stakes and string.
2. One partner will scatter the toothpicks randomly throughout the square. The other partner will have 1 minute to pick up as many toothpicks as possible, one at a time. Repeat this procedure until each team has performed five trials.
3. Record your team's results in a data table.

Analysis Which colors of toothpicks were picked up most often? Which were picked up least often? How do you account for this difference?

(a)

(b)

FIGURE 21-4

The ticks in (a) are ectoparasites that can sicken and occasionally kill their host by infection or disease. A tapeworm, the endoparasite shown in (b), can grow to 20 m or more in length and can cause illness and death by intestinal blockage and by robbing its host of nutrition.

such as the eyes, mouth, and nose, are defended chemically by tears, saliva, and mucus. Parasites that get past these defenses still may be attacked by the cells of the immune system. Figure 21-4 shows two examples of parasites.

Adaptations of Parasites

Natural selection favors adaptations that allow a parasite to efficiently exploit its host. Parasites are usually specialized anatomically and physiologically. Tapeworms are so specialized for a parasitic lifestyle that they do not even have a digestive system. They live in the small intestine of their host and absorb nutrients directly through their skin.

COMPETITION

Competition results from fundamental niche overlap—the use of the same limited resource by two or more species. Some species of plants release toxins into the soil that prevent individuals of other species from growing nearby, restricting the living space of the other species. More often, one organism will be able to use a resource more efficiently, leaving less of the resource available to the other species.

Research Studies on Competition

Soviet ecologist G. F. Gause was one of the first to study competition in the laboratory. In test tubes stocked with a food supply of bacteria, Gause raised some species of paramecia, separately and in various combinations. *Paramecium caudatum* and *Paramecium aurelia* thrived when grown separately. As you can see in Figure 21-5, when the two species were combined, *Paramecium caudatum* always died out because *Paramecium aurelia* was a more efficient predator of bacteria. Ecologists use the principle of **competitive exclusion** to describe situations in which one species is eliminated from a community because of competition for the same limited resource. In competitive exclusion, one species uses the resource

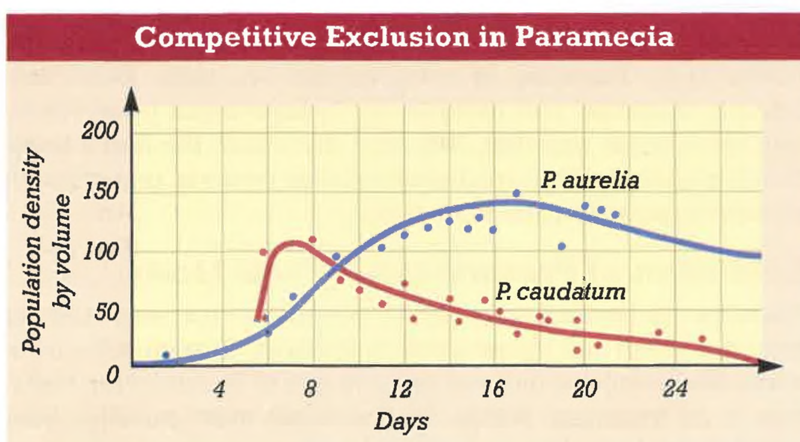


FIGURE 21-5

The graph shows the negative effect of competition on populations. When *Paramecium aurelia* and *Paramecium caudatum* were grown separately, they each grew to twice the density that they reached when they were grown together, as shown. When grown together, *Paramecium aurelia* proved to be the better competitor for the available food resource. Eventually, *Paramecium caudatum* died out because it could not compete for food.

more efficiently and has a reproductive advantage that eventually eliminates the other species.

Joseph Connell's study of barnacles along the Scottish coast in the 1960s demonstrates competition in the wild. Connell studied two species of barnacles, *Semibalanus balanoides* and *Chthamalus stellatus*, that live in the intertidal zone, the portion of the shore that is exposed during low tide. Each species formed a distinct band within the intertidal zone, as shown in Figure 21-6, with *Chthamalus* living higher on the rocks than *Semibalanus* did. Connell demonstrated that this difference was partly due to competition. When a rock covered with *Chthamalus* was transplanted to the lower zone, *Chthamalus* was clearly able to tolerate the conditions in the lower zone. However, *Semibalanus* settled on the rock and eventually crowded out *Chthamalus*. Connell concluded that competition restricted the range of *Chthamalus*. Although it could survive lower on the rocks, competition from *Semibalanus* prevented it from doing so. Intolerance to long periods of drying when the tide was out probably restricted the range of *Semibalanus* to the lower zone.

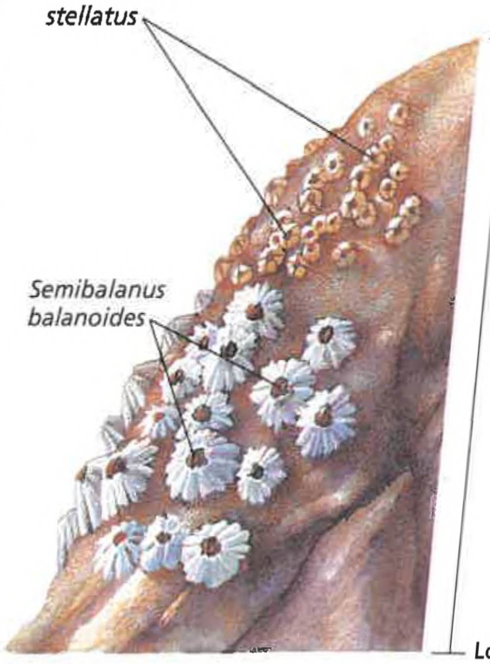


FIGURE 21-6

Although *Chthamalus* is capable of surviving in the lower intertidal zones, it is crowded out by *Semibalanus*. *Semibalanus* is unable to survive in the upper zone, which is frequently above the tidal level for extended periods. *Semibalanus* is the most efficient competitor in the areas that are usually under water.

Competition and Community Structure

Competition has the potential to be an important influence on the nature of a community. The composition of a community may change through competitive exclusion. Competitors may also evolve niche differences or anatomical differences that lessen the intensity of competition. Natural selection favors differences between potential competitors. These differences are often greatest where the ranges of potential competitors overlap. This phenomenon is called **character displacement.**

An example of character displacement is provided by Darwin's finches. These finches feed on seeds. Birds with larger beaks can crack open and eat larger seeds, so beak size is a good indicator of diet. Two species of Darwin's finches are very similar to each other. On islands where only one of two similar species is found, birds of the two species have the same size beak. But on an island where both birds are found, their beak sizes are different. They have evolved a character displacement that enables them to feed on different-sized seeds and reduce competition.

As Darwin noted, competition is likely to be most intense between closely related species that require the same resources. When similar species coexist, each species uses only part of the available resources. This pattern of resource use is called **resource partitioning.** For example, consider three species of warblers that live in spruce and fir trees and feed on insects. The late Princeton ecologist Robert MacArthur discovered that the warblers differ in where they forage. Each kind of warbler hunts for insects only in a particular section of the tree. As a result, competition among the species is reduced.

internetconnect
SCiLINKS NSTA
TOPIC: Competition
GO TO: www.scilinks.org
KEYWORD: HM401

MUTUALISM AND COMMENSALISM

Mutualism is a cooperative relationship in which both species derive some benefit. Some mutualistic relationships are so close that neither species can survive without the other. An example of such mutualism involves ants and a shrub called bull's horn acacia. The ants nest inside the acacia's large thorns and receive food from the plant. The ants protect the acacia from predation by herbivores and trim back vegetation that shades the shrub.

Pollination is one of the most important mutualistic relationships on Earth. Animals such as bees, butterflies, flies, beetles, bats, and birds pollinate many flowering plants. Animals that carry pollen are called **pollinators.** A flower is a lure for pollinators, which are attracted by the flower's color, pattern, shape, or scent. The plant usually provides food for its pollinators. As the animal feeds in the flower, it picks up a load of pollen, which it will carry to the next flower of the same species it visits, as shown in Figure 21-7.

FIGURE 21-7

Some bats are active at night and locate their food by sound or smell instead of by sight. Flowers pollinated by nectar-feeding bats do not need to be brightly colored, but they usually do have a strong fragrance. As the bat feeds on the flower's nectar, it becomes smeared with pollen, as shown. The bat then carries the pollen to the next flower it feeds on.

Commensalism is an interaction in which one species benefits and the other is not affected. Some cases of commensalism may be mutualisms in which the benefit to the second organism hasn't yet been identified. One example of commensalism is the relationship between cattle egrets and Cape buffalo in Tanzania. The birds feed on small animals such as insects and lizards that are forced out of their hiding places by the buffalo's movement through the grass.

SECTION 21-1 REVIEW

1. Explain how predators differ from parasites. Give an example of each kind of organism.
2. Some harmless flies resemble bees and wasps. What is this mechanism called? Evaluate its importance as a defense mechanism.
3. Describe two chemical defenses of plants.
4. Explain the advantage of character displacement and give an example.
5. If cattle egrets removed ticks from Cape buffalo, would their relationship still be considered commensalism? Explain your answer.
6. CRITICAL THINKING Explain how two similar species of birds are able to inhabit the same area and even nest in the same tree without occupying the same niche.

PROPERTIES OF COMMUNITIES

The investigation of community properties and interactions is an active area of ecology. What properties are most significant in structuring a community? What determines species richness and abundance? These questions are central to a study of communities.

SECTION

21-2

OBJECTIVES

▲ Explain the difference between species richness and species diversity.

● Describe how species richness varies with latitude, and explain a hypothesis for this pattern.

■ Explain the cause and consequences of the species-area effect.

◆ Explain the two main views of the relationship between species richness and stability.

SPECIES RICHNESS AND DIVERSITY

One characteristic of a community is its **species richness,** the number of species it contains. A related measure is **species diversity,** which relates the number of species in the community to the relative abundance of each species. These two measures provide slightly different information. Species richness is a simple count of the species in the community. Each species contributes one count to the total, regardless of whether the species' population size is one or 1 million. In contrast, species diversity suggests each species' importance because it takes into account how common each species is in the community. To calculate the species diversity of a community, an ecologist must measure or estimate the population size of all the species in the community.

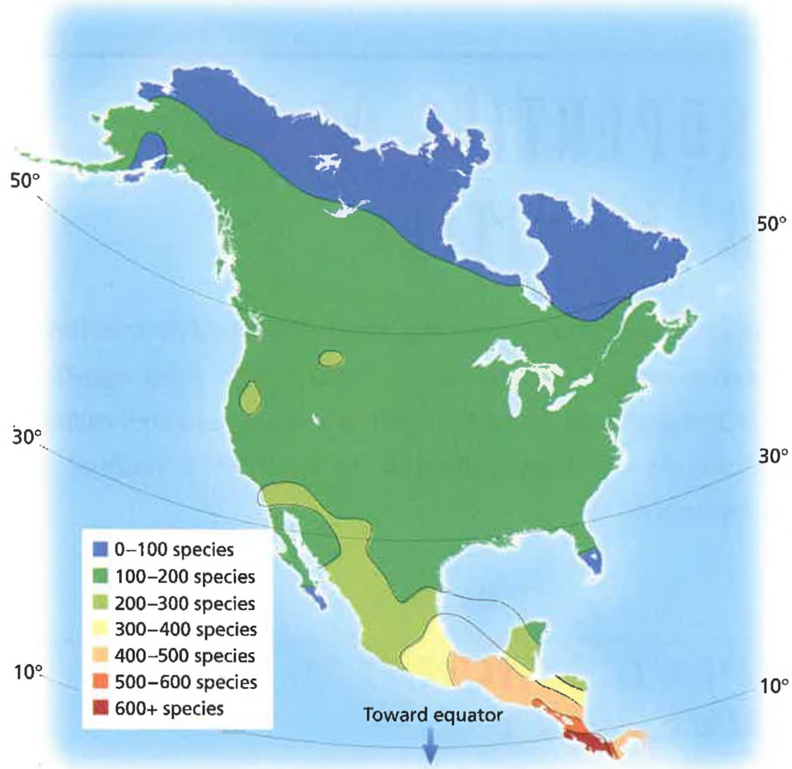
Patterns of Species Richness

Species richness varies with latitude (distance from the equator). As a general rule, the closer a community is to the equator, the more species it will contain. Species richness is greatest in the tropical rain forests. For example, entomologists E. O. Wilson and Terry Erwin identified nearly as many species of ants in a single tree in Peru as can be found in the entire British Isles.

Why are there more species in the tropics than there are in the temperate zones? One hypothesis is that temperate habitats are younger, having formed since the last ice age. Therefore, tropical habitats were not disturbed by the ice ages, while habitats at latitudes farther north were. Also, the climate is more stable in the tropics. This stability allowed species to specialize to a greater degree than they could in temperate regions, where the climate is more variable. Another hypothesis suggests that because plants

FIGURE 21-8

This species-richness map of North American and Central American birds shows that fewer than 100 species of birds inhabit arctic regions, whereas more than 600 species occupy some tropical regions. This is evidence that species richness increases nearer the equator. Equatorial rain forests are biologically the richest habitats on Earth.



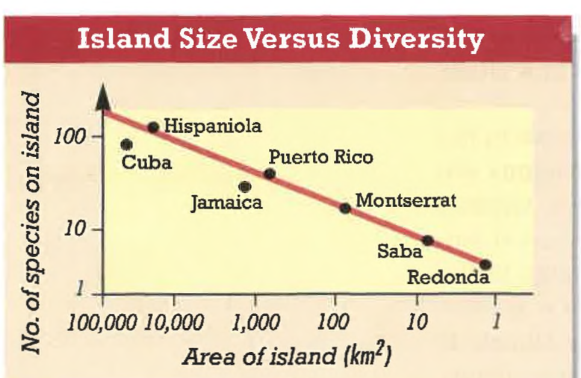
can photosynthesize year-round in the tropics, there is more energy available to support more organisms. It is likely that the high diversity of species in the tropics, as indicated in Figure 21-8, is the result of several factors acting together.

FIGURE 21-9

As shown in the graph, the large islands of Cuba and Hispaniola have about 100 species (of reptiles and amphibians). The small island of Redonda has only about five species of reptiles and amphibians. In general, species diversity increases as available habitat area increases. This principle is true whether the boundaries of the area are created by shoreline, as on an island, or by encroaching human population, as in the construction of housing in a natural area.

The Species-Area Effect

Another pattern of species richness is that larger areas usually contain more species than smaller areas do. This relationship is called the **species-area effect.** The species-area effect is most often applied to islands, where area is clearly limited by geography. In the Caribbean, for example, more species of reptiles and amphibians live on large islands, such as Cuba, than on small islands, such as Redonda, as shown in Figure 21-9. Because all of these islands are close together, differences in species richness cannot be due to differences in latitude. Why does species richness increase with increasing area? Larger areas usually contain a greater diversity of habitats and thus can support more species.



The species-area effect has one very important practical consequence—reducing the size of a habitat reduces the number of species it can support. Today, natural habitats are shrinking rapidly under pressure from the ever-growing human population. About 2 percent of the world's tropical rain forests is destroyed each year, for example. The inevitable result of the destruction of habitats is the extinction of species.

Species Interactions and Species Richness

Interactions among species sometimes promote species richness. Several studies have demonstrated that predators can prevent competitive exclusion from occurring among their prey. In the 1960s, Robert Paine of the University of Washington showed the importance of the sea star *Pisaster,* shown in Figure 21-10, in maintaining the species richness of communities on the Washington coast. Paine removed all *Pisaster* individuals from one site and for several years prevented any new *Pisaster* individuals from settling there. This change caused a dramatic shift in the community. The mussel *Mytilus,* which had previously coexisted with several other species, became much more abundant and spread over the habitat, crowding out other species. The species richness of the community fell from 15 to 8 during the course of the study. Evidently, *Mytilus* was the superior competitor for space on the rocks, but its population was normally held in check by predation from *Pisaster.*

FIGURE 21-10

When the sea star *Pisaster* was removed from an area where the sea stars had preyed on the mussel *Mytilus,* the mussels crowded out many of the other competing species in the area. Predation by the sea star on the mussel promoted diversity by controlling the superior competitor—the mussel.

Community Stability

One of the most important characteristics of a community is how it responds to disturbance. The **stability** of a community indicates its resistance to change. For many years, most ecologists agreed that stability was directly related to species richness. Communities with more species, they presumed, would contain more links between species. These links would, in a sense, disperse the effects of the disturbance and prevent disruption of the community. One line of evidence cited in support of this view was the vulnerability of agricultural fields, which usually contain one species of crop plant, to outbreaks of insect pests.

David Tilman of the University of Minnesota and John Dowling of the University of Montreal investigated how the response to drought in a small plot of grasses was affected by species richness. They grew varying numbers of species in many small plots of land and subjected each to drought. They found that plots with more species present lost a smaller percentage of plant mass than plots with fewer species. The plots with more species also took less time to recover from the drought. They concluded that species richness improves a community's stability.

internet**connect**

SCILINKS NSTA

TOPIC: Species interaction and richness
GO TO: www.scilinks.org
KEYWORD: HM405

SECTION 21-2 REVIEW

1. **What is the difference between species richness and species diversity?**
2. **Explain the relationship between species richness and latitude.**
3. **Why is the species-area effect important in efforts to conserve species?**
4. **Describe how predation can affect species diversity.**
5. **Explain how species richness contributes to community stability.**
6. **CRITICAL THINKING Explain how the example of agricultural fields supports the idea that species richness promotes stability.**

SECTION

21-3

OBJECTIVES

▲

Distinguish between primary and secondary succession.

●

Identify some of the characteristics of pioneer species.

■

Describe the sequence of changes occurring at Glacier Bay.

◆

Explain the successional changes that can occur when an existing community is disrupted.

internetconnect

SCILINKS NSTA

TOPIC: Succession
GO TO: www.scilinks.org
KEYWORD: HM406

SUCCESSION

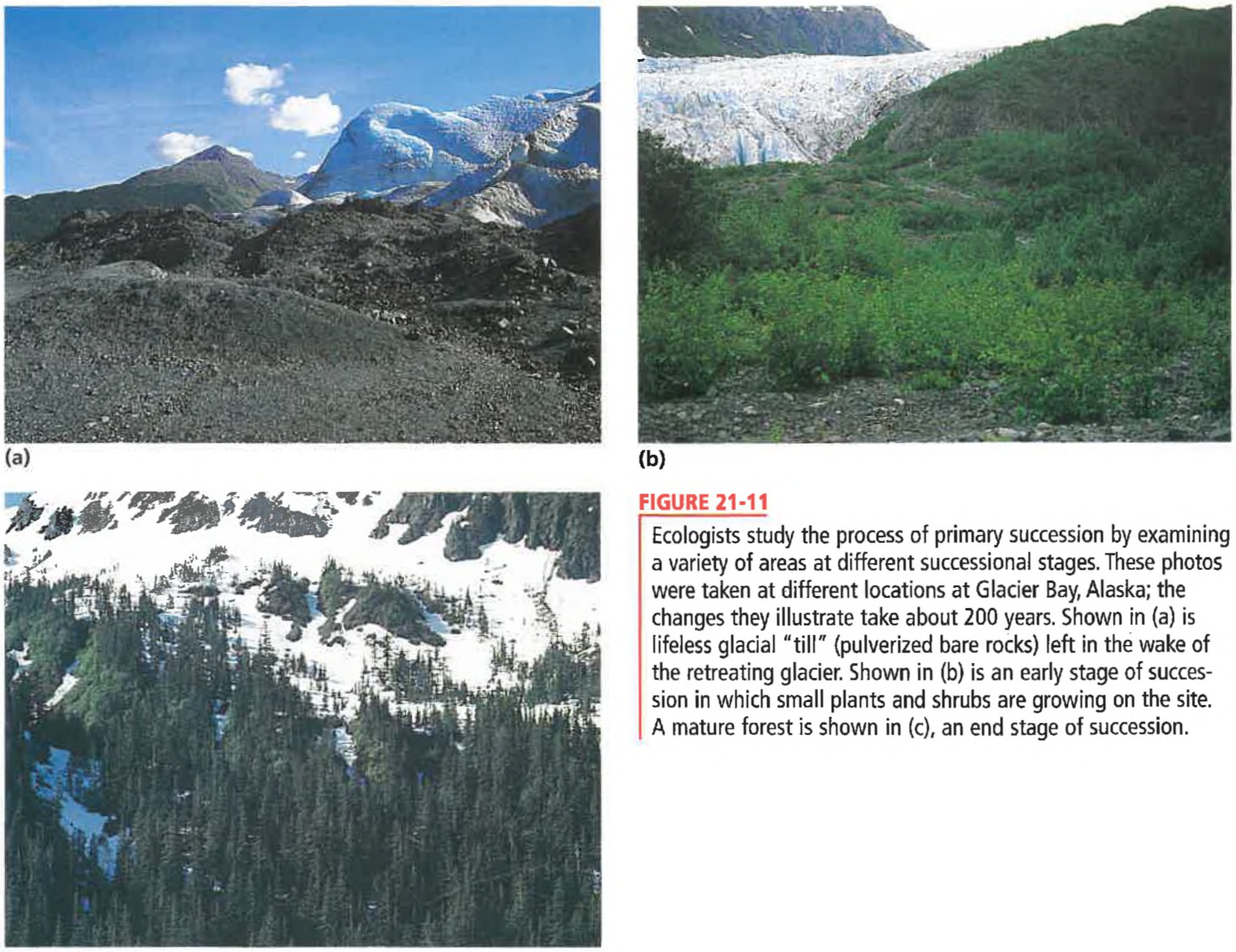
Disturbances such as fires, landslides, hurricanes, and floods trigger a sequence of changes in the composition of a community. Certain species flourish immediately after the disturbance, then are replaced by other species, which are replaced by still others. Over time, the composition of the community changes.

SUCCESSIONAL CHANGES IN COMMUNITIES

During the summer and early fall of 1988, fires burned large areas of Yellowstone National Park, affecting nearly 300,000 hectares (720,000 acres). If you visit Yellowstone today, you will find that regrowth is well under way in the burned areas. In time, if there are no further disturbances, the burned areas of Yellowstone National Park will undergo a series of regrowth stages. The gradual, sequential regrowth of species in an area is called **succession** (SUHK-SE-shuhn). You can see early stages of succession in abandoned fields, in vacant lots, along roads, and even in sidewalks or parking lots where weeds are pushing up through cracks in the concrete.

Ecologists recognize two types of succession. **Primary succession** is the development of a community in an area that has not supported life previously, such as bare rock, a sand dune, or an island formed by a volcanic eruption. **Secondary succession** is the sequential replacement of species that follows disruption of an existing community. The disruption may stem from a natural disaster, such as a forest fire or a strong storm, or from human activity, such as farming, logging, or mining.

Any new habitat, whether it is a pond left by heavy rain, a freshly plowed field, or newly exposed bedrock, is an invitation to many species that are adapted to be good pioneers. The species that predominate early in succession—called the **pioneer species**—tend to be small, fast-growing, and fast-reproducing. Pioneer species are well suited for invading and occupying a disturbed habitat. For example, they are often very good at dispersing their seeds, which enables them to quickly reach disrupted areas. Some of the pioneers that might be found in a vacant lot or abandoned field in the eastern United States include horseweed, crabgrass, and ragweed.



(a) (b) (c)

FIGURE 21-11

Ecologists study the process of primary succession by examining a variety of areas at different successional stages. These photos were taken at different locations at Glacier Bay, Alaska; the changes they illustrate take about 200 years. Shown in (a) is lifeless glacial "till" (pulverized bare rocks) left in the wake of the retreating glacier. Shown in (b) is an early stage of succession in which small plants and shrubs are growing on the site. A mature forest is shown in (c), an end stage of succession.

Primary Succession

Primary succession often proceeds very slowly because the minerals necessary for plant growth are unavailable. For example, when glaciers last retreated from eastern Canada, about 12,000 years ago, they left a huge stretch of barren bedrock from which all the soil had been scraped. This geologic formation, called the Canadian Shield, was a place where plants and most animals could not live. Repeated freezing and thawing broke this rock into smaller pieces. In time, lichens—mutualistic associations between fungi and either algae or cyanobacteria—colonized the barren rock. Acids in the lichens and mildly acidic rain washed nutrient minerals from the rock. Eventually, the dead organic matter from decayed lichens along with minerals from the rock began to form a thin layer of soil in which a few grasslike plants could grow. These plants then died, and their decomposition added more organic material to the soil. Soon shrubs began to grow, and then trees appeared. Today much of the Canadian Shield is densely populated with pine, balsam, and spruce trees, whose roots cling to soil that in some areas is still only a few centimeters deep. A similar series of changes has been documented at Glacier Bay, Alaska, shown in Figure 21-11.

(a)

(b)

(c)

FIGURE 21-12

In (a), a recently abandoned agricultural field is being pioneered by weeds. Eventually, taller plants and shrubs will shade out the pioneers, as shown in (b). Next, a forest of pine or cottonwood may be succeeded by a hardwood forest. The whole process, if there are no further disturbances, takes about 100 years.

Secondary Succession

Secondary succession occurs where an existing community has been cleared by a disturbance, such as agriculture, but the soil has been left intact. In secondary succession, it commonly takes about 100 years for the original ecosystem to return through a series of well-defined stages. In eastern temperate regions, secondary succession typically begins with annual grasses, mustards, and dandelions. Succession proceeds with perennial grasses and shrubs, continues with trees like dogwoods, and often continues to a deciduous forest, as shown in Figure 21-12.

THE COMPLEXITY OF SUCCESSION

The traditional description of succession is that the community proceeds through a predictable series of stages until it reaches a stable end point, called the **climax community.** The organisms in each stage alter the physical environment in ways that make it less favorable for their own survival but more favorable for the organisms that eventually succeed them. In a sense, each stage paves the way for the next, leading ultimately to the climax community, which remains constant for a long period of time.

When ecologists began to study and document many instances of succession, they found a complex picture. Some so-called climax communities, for example, are not stable and continue to change. Instead of proceeding inevitably toward the climax community, succession may be regularly "reset" by disturbances. For example, many grasslands give way to forests, but periodic fires prevent the forests from developing. There may be many possible successional pathways in a particular area. The actual path followed may depend on the identities of the species present, the order in which they arrive, the climate, and many other factors. Ecologists agree that the idea of a single successional pathway ending in a stable climax community is too simple to describe what actually occurs in nature.

SECTION 21-3 REVIEW

1. **What is the difference between primary succession and secondary succession?**
2. **How are plants we think of as weeds, such as ragweed, well adapted to be pioneer species?**
3. **Identify one of the initial colonists in succession at Glacier Bay.**
4. **Describe secondary succession, and distinguish between pioneer species and a climax community.**
5. **How do frequent fires alter succession in a community?**
6. **CRITICAL THINKING Describe the geological process of soil formation. Explain its importance to succession.**

CHAPTER 21 REVIEW

SUMMARY/VOCABULARY

21-1

- Ecologists recognize five major kinds of species interactions in communities: predation, parasitism, competition, mutualism, and commensalism.
- The interaction in which one organism kills and eats another is predation. Predators have evolved many ways to efficiently find and capture prey. Prey have evolved many ways to defend themselves against predators.
- Mimicry is a defense mechanism in which a harmless species gains protection by its resemblance to a poisonous or distasteful species, or in which two or more poisonous or distasteful species resemble each other.
- Parasitism involves one organism feeding on, but not always killing, another. Parasites are grouped into two general categories—external parasites (ectoparasites) and internal parasites (endoparasites).
- Competition occurs when two or more species use the same scarce resource.
- Competition may cause competitive exclusion, the extinction of one competitor from the community. It may also be a strong selective force in the evolution of niche differences among competitors.
- In mutualism, both interacting species benefit. The relationship between flowering plants and their pollinators is an example of mutualism.
- In commensalism, one species benefits and the other is not affected.

Vocabulary

character displacement (401)
commensalism (402)
competition (400)
competitive exclusion (400)
ectoparasite (399)
endoparasite (399)
herbivore (398)
host (399)
mimicry (398)
mutualism (402)
parasite (399)
parasitism (399)
pollinator (402)
predator (397)
prey (397)
resource partitioning (401)
secondary compound (398)
symbiosis (397)

21-2

- Species richness is the number of species in a community.
- Species diversity incorporates both species richness and the abundance of each species.
- As a general rule, species richness is greatest near the equator.
- Larger areas generally support more species. This is called the species-area effect.
- Species interactions such as predation can promote species richness.
- Species richness improves a community's stability.

Vocabulary

species-area effect (404)
species diversity (403)
species richness (403)
stability (405)

21-3

- Succession is a change in the species composition of a community. Primary succession is the assembly of a community on newly created habitat. Secondary succession is the change in an existing community following a disturbance.
- Pioneer species are the initial colonists of a disturbed area. They are usually small organisms that grow fast, reproduce quickly, and disperse their seeds well.
- Succession at Glacier Bay proceeded from bare debris left behind by a retreating glacier to small plants such as mosses, to alders, to spruce and hemlocks.
- Secondary succession occurs in areas where the original ecosystem has been cleared by a disturbance, such as clearing for agriculture. It proceeds from plants commonly thought of as weeds to a stable end point called a climax community.

Vocabulary

climax community (408)
pioneer species (406)
primary succession (406)
secondary succession (406)
succession (406)

REVIEW

Vocabulary

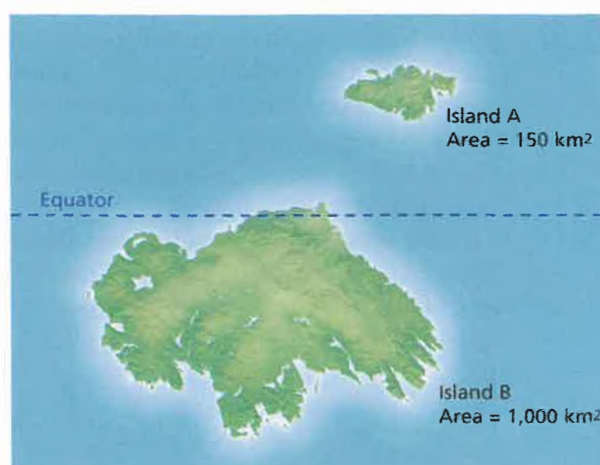
1. Explain the difference between mutualism and commensalism.
2. Describe resource partitioning and competition, and explain how they are related.
3. What is the difference between ectoparasites and endoparasites?
4. How do competitive exclusion and character displacement differ?
5. Distinguish between species richness and the species-area effect.

Multiple Choice

6. In which of the following interactions do both species benefit? (a) competition (b) predation (c) mutualism (d) commensalism
7. An example of a parasite is (a) a lion (b) a tick (c) a deer (d) a snake.
8. Which of the following is not a plant defense against herbivores? (a) thorns (b) tough leaves (c) secondary compounds (d) lysozyme
9. The evolution of anatomical differences in response to competition is called (a) competitive exclusion (b) character displacement (c) niche release (d) convergence.
10. Which of the following is true of a mimic?
    (a) It is poisonous or distasteful.
    (b) It is identical to a poisonous species.
    (c) It closely resembles a poisonous species.
    (d) An example is the coral snake.
11. Species richness (a) is greater on large islands than it is on small islands (b) is lowest in the tropics (c) is increasing worldwide (d) is greater on small islands than on large islands.
12. In the experiment with the sea star *Pisaster* and the mussel *Mytilus,* (a) elimination of the mussel *Mytilus* increased the number of sea stars (b) species richness of the community increased over time (c) removal of the sea star led to a decrease in species richness (d) removal of the sea star led to an increase in species diversity.
13. Primary succession occurs (a) on bare rock (b) in a disrupted habitat (c) after a forest fire (d) only on dry land.
14. The feeding behavior of warblers is an example of (a) niche overlap (b) resource partitioning (c) mutualism (d) character displacement.
15. Which is not true of secondary compounds?
    (a) They are part of a defense mechanism.
    (b) They can be poisonous and taste bad.
    (c) They are metabolized as food by plants.
    (d) They compose the irritant produced by poison ivy.

Short Answer

16. Describe two evolutionary adaptations that enable organisms to be efficient predators.
17. What are secondary compounds, and what is their function? List two examples of secondary compounds.
18. Explain some of the ways your body defends itself against parasites.
19. Describe the experiments G. F. Gause conducted on competition in *Paramecium.* What were the results of these experiments?
20. In the study of competition between two species of barnacles, *Semibalanus* was clearly the superior competitor, yet *Chthamalus* was not excluded from the community. Explain why.
21. What benefits do ants derive from their relationship with the bull's horn acacia? What benefits does the acacia receive from the ants?
22. Examine the island map below. Which island will probably have more species of plants and animals, Island A or Island B? Explain your answer.



23. Unit 7—*Ecosystem Dynamics*

BIOLOGY INTERACTIVE TUTOR Write a report summarizing how artificial ecosystems, used in the management and treatment of wastewater and pollutants, can demonstrate succession.

CRITICAL THINKING

1. A scientist studies a community and finds no evidence of competition. The scientist concludes that competition has never had an effect on the structure of the community. Is this a valid conclusion? Explain your answer.
2. Some plants are pollinated by only one pollinator. Explain why this might be advantageous to the plant. Explain why this specificity could also lead to the extinction of the plant species.
3. Explain why it is usually harder to measure the species diversity of a community than it is to measure its species richness.
4. Examine the figure of the warblers on the right.
   a. Each bird is shown in the part of the tree where it usually nests. Explain how three closely related species of warbler are able to coexist in the same tree. What phenomenon is demonstrated by their coexistence?
   b. What might happen if only a single species of insect inhabited the spruce tree? Explain the phenomenon that might be demonstrated in this case.
   c. Suppose the birds are seed-eating finches and the tree produces large and small seeds. Each of the birds has either a small beak or a large beak. Explain the evolutionary phenomenon demonstrated in this case. Would a bird with a medium-sized beak be able to coexist in the tree? Explain why or why not.

EXTENSION

1. Ants have mutualistic relationships with a variety of different organisms. Use an on-line database or conduct library research to identify two mutualisms (besides those mentioned in the text) between ants and other species. Write a report that summarizes what you have learned. Be sure to explain the nature of each interaction and the benefits each species receives.
2. Read "Hidden Existence" in *Audubon,* March–April 1999, on page 56. Describe two ways some animals are able to hide in plain view. Explain how an animal might combine camouflage coloration with specialized behavior to avoid predators. Camouflage is important to prey animals, but how does it help predators?
3. Choose two flowering plants that live in your area. Find out what pollinators visit the flowers. Make drawings that show the flowers and their pollinators.

CHAPTER 21 INVESTIGATION

Nitrogen Fixation in Root Nodules

OBJECTIVES

- Examine root nodules in legumes.
- Investigate the differences between legume (bean) and a nonlegume (radish).
- View active cultures of *Rhizobium.*

PROCESS SKILLS

- recognizing relationships
- hypothesizing
- comparing and contrasting

MATERIALS

- protective gloves
- 2 three-inch flowerpots
- 2 cups of soil
- 2 mixing sticks
- 1.2 mL (1/4 tsp) of *Rhizobium* bacteria per pot
- 2 bean seeds
- 2 radish seeds
- 2 microscope slides
- 2 coverslips
- 1 prepared reference slide of a legume root-nodule cross-section infected with *Rhizobium*
- compound light microscope
- stereoscope or magnifying glass
- scalpel

Background

1. Define *symbiosis,* and give an example of three types of symbiotic associations.
2. Nitrogen-fixing bacteria and leguminous plants have a symbiotic relationship.
3. Root nodules are swellings in the roots of leguminous plants that are infected with nitrogen-fixing bacteria.
4. *Rhizobium* is a genus of nitrogen-fixing bacteria. *Rhizobium* exists in soil and infects the root nodules of leguminous plants.
5. Green root nodules indicate actively reproducing bacteria that are not fixing nitrogen. Pink nodules indicate bacteria that are actively fixing nitrogen but not reproducing.

PART A Growing the Test Plants

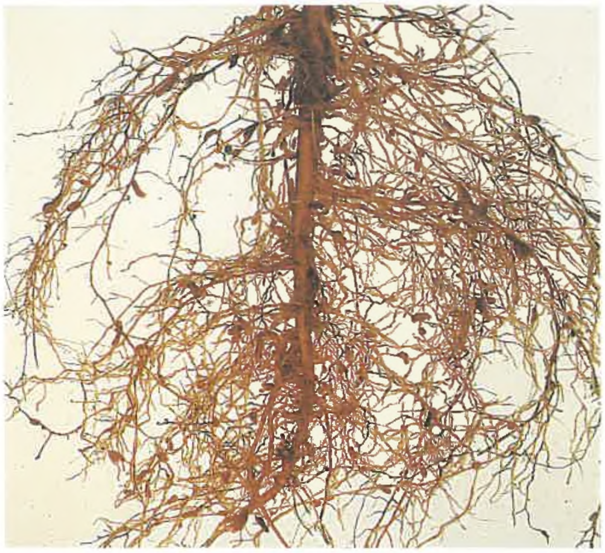
1. Fill two flowerpots with soil. Using a mixing stick, stir approximately 1/4 teaspoon of the *Rhizobium* mixture into each pot.
2. Plant two bean seeds in one pot and label it "bean," and two radish seeds in the other and label it "radish." Water each pot so that the soil is moist but not saturated. Label the two pots.
3. Place the plants where they will receive direct sunlight. Water the soil when necessary to keep the soil moist but not saturated. Do not fertilize these plants.
4. After approximately one week, check to see if both seeds germinated in each pot. If they did, remove the smaller seedling. The plants will be ready to be examined after six to eight weeks. Monitor the plants each day. Give them enough water to keep the soil slightly moist, and keep them in direct sunlight. Note: The radish seeds will germinate faster than the bean seeds.
5. Clean up your materials and wash your hands before leaving the lab.

PART B Observing the Roots of Beans

6. Prepare a data table similar to the one below. As you work, record your observations in your data table.
7. CAUTION **Wear disposable gloves while handling plants. Do not rub any plant part or plant juice on your eyes or skin.** Remove the bean plant from the pot by grasping the bottom of the stem and gently pulling the plant out. Be careful not to injure the plant. Carefully remove all dirt from the roots.
8. View the roots of the bean plant under a stereoscope. Compare the appearance of the bean root system

OBSERVATIONS OF RHIZOBIUM

Appearance of nodule	
Color of nodule	
Number of nodules	
Number of pink nodules	
Number of green nodules	



with the photograph above. Note the formation of any nodules on your bean plant's roots. Draw a root with a nodule in your lab report, and label each structure.

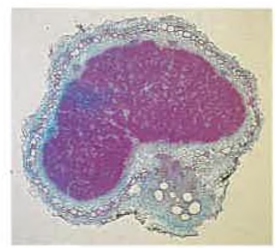
9. **CAUTION Use the scalpel with care. A scalpel is a very sharp instrument. Always make cuts with the blade facing away from your body. If you cut yourself, quickly apply direct pressure to the wound and call for your teacher.** Remove a large nodule from the bean root and carefully cut it in half with a scalpel. The pink nodules contain active nitrogen-fixing bacteria. The green nodules contain bacteria but cannot fix nitrogen because they are actively reproducing. *Rhizobium* will begin fixing nitrogen only after it stops reproducing. View the cross section under a stereoscope. Note the arrangement of bacteria within the cell. Draw a cell infected with bacteria in your lab report. Label the nodule, cell, and bacteria.

PART C Observing the Roots of Radishes

10. **CAUTION Wear disposable gloves while handling plants. Do not rub any plant part or plant juice on your eyes or skin.** Remove the radish plant from the pot by grasping the bottom of the stem and gently pulling the plant out. Be careful not to injure the plant. Carefully remove all dirt from the roots.
11. Examine the roots of the radish plant under a stereoscope. Compare the radish roots with the roots of the bean plant that you have already examined. Are there any nodules on the roots of the radish plant? Draw the root of the radish plant in your lab report. Label the drawing "Radish."

PART D Preparing a Wet Mount of *Rhizobium*

12. **CAUTION Handle the slide and coverslip carefully. Glass slides break easily and the sharp edges can cut you.** Prepare a wet mount by placing part of a nodule from the root of a bean plant on a microscope slide, adding a drop of water, and covering with a coverslip.
13. Place the slide on a flat surface. Gently press down on the slide with your thumb; use enough pressure to squash the nodule. Make sure the coverslip does not slide.
14. Examine the slide under a microscope. Draw and label a cell and the arrangement of bacteria in the cell in your lab report. Note what power of magnification you used.
15. Compare your wet mount preparation with the prepared reference slide of *Rhizobium* and the photograph on the right. A cell infected with *Rhizobium* should have a similar appearance to the photograph at right.



16. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. Which plant had the most nodules?
2. How many nodules were found on the radish plants?
3. How do legumes become infected with bacteria in nature?
4. What kind of relationship exists between the legume plant and *Rhizobium*? How does this relationship benefit the legume plant? How does this relationship benefit the bacteria?
5. If you were to grow legumes without root nodules to use as experimental controls, why should you plant the seeds in sterile soil?

Further Inquiry

Perform the experiment using beans with and without *Rhizobium.* Count the number of leaves on each plant, and measure the mass of each whole plant as well as the masses of roots, stems, and leaves separately. Predict which part of the plant will have the greatest difference in mass.

CHAPTER 22

ECOSYSTEMS AND THE BIOSPHERE

Tropical rain forests are the most biologically diverse of all the biomes on Earth. Shown is the scarlet macaw, Ara macao.

FOCUS CONCEPT: *Interdependence of Organisms*

As you read, note how organisms interact with each other and with their environment to survive in the different kinds of ecosystems on Earth.

BIOLOGY INTERACTIVE TUTOR
Unit 7—*Ecosytem Dynamics*
Topics 1, 3–6

SECTION

22-1

OBJECTIVES

▲ Contrast producers with consumers.

● Explain the important role of decomposers in an ecosystem.

■ Contrast a food web with a food chain.

◆ Explain why ecosystems usually contain only a few trophic levels.

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, 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 have an important effect on 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.** 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-mo-SIN-thuh-sis), which means they produce carbohydrates by using energy from inorganic molecules. 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 energy. Photosynthetic producers use the energy they capture to make sugar. Some of the sugar is used for cellular respiration, some for maintenance and repair, and some to make new organic material through either growth or reproduction. Ecologists refer to the organic material 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, and this rate is called **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 mass per unit area per year (g/m^2/y). Net primary productivity equals gross primary productivity minus the rate of respiration in producers.

Figure 22-1 shows that net primary productivity can vary greatly from one ecosystem to another. For example, the average rate of net

internetconnect

SCILINKS NSTA

TOPIC: Producers and consumers
GO TO: www.scilinks.org
KEYWORD: HM415

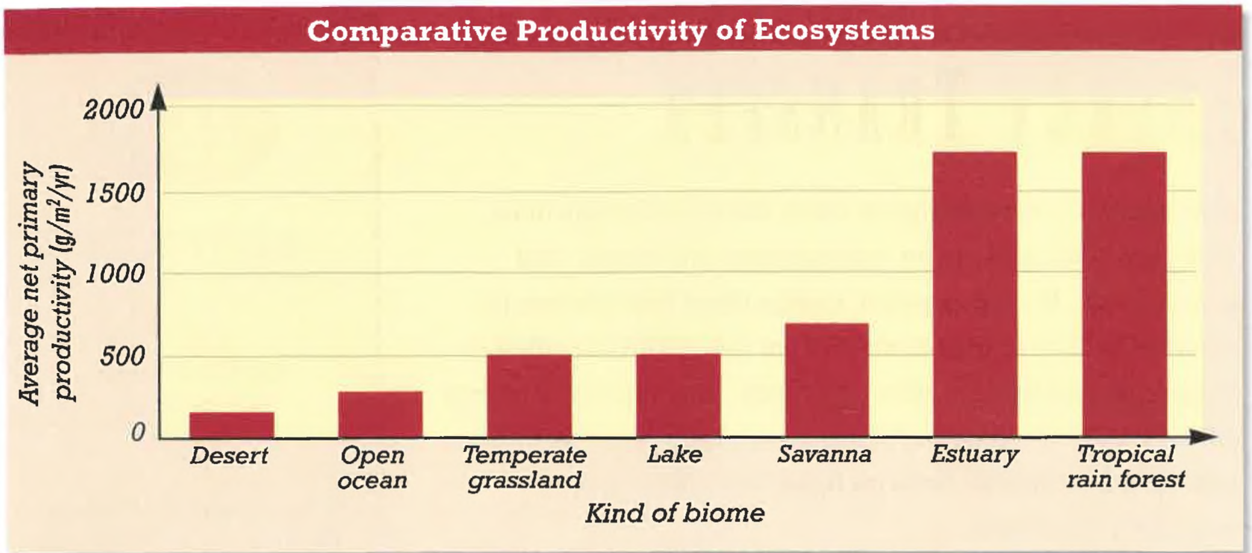


FIGURE 22-1

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.

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 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 three variables usually leads to an increase in productivity. In aquatic ecosystems, productivity is usually determined by only two factors: light and the availability of nutrients.

CONSUMERS

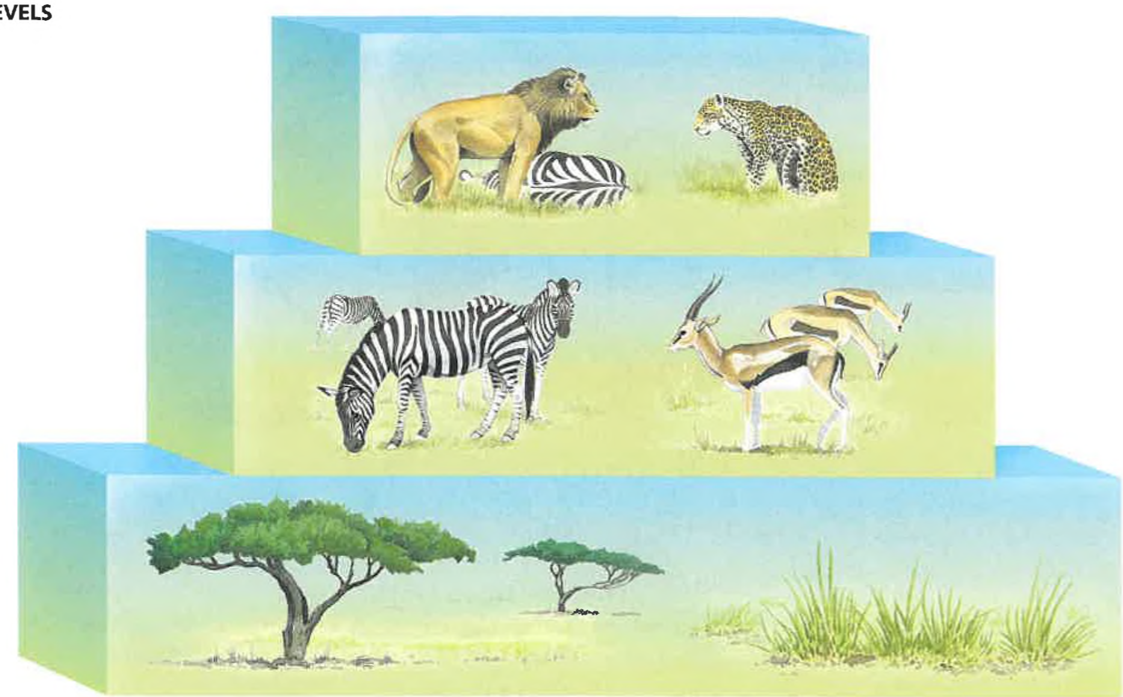
All animals, most protists, all fungi, and many bacteria are heterotrophs. Unlike autotrophs, heterotrophs cannot manufacture their own food. Instead they get energy by eating other organisms or organic wastes. Ecologically speaking, heterotrophs are **consumers.** They obtain energy by consuming organic 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. So are the minute zooplankton that feed on phytoplankton floating in oceans and lakes. **Carnivores** eat other consumers. Lions, bald eagles, 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-TRIE-ti-vorz) are consumers that feed on the "garbage" of an ecosystem, such as organisms that have recently died, fallen leaves and branches, and animal wastes. A vulture is an example of a detritivore. Bacteria and fungi belong to a class of detritivores called decomposers. **Decomposers** cause decay by breaking down the complex molecules in dead tissues and wastes into simpler

Word Roots and Origins

omnivore

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



molecules. Some of the molecules released during decay are absorbed by the decomposers, and some of them are returned to the soil or water. The action of the decomposers makes the nutrients contained in the dead bodies and wastes of organisms available to autotrophs. Thus, the process of decomposition recycles chemical nutrients.

FIGURE 22-2
In an ecosystem, all organisms that feed on the same kind of food are in the same trophic level. In this figure, the autotrophs (grass and tree) are on the first trophic level, herbivores (zebra and giraffe) are on the second trophic level, and carnivores (lion and leopard) are on the third trophic level.

ENERGY FLOW

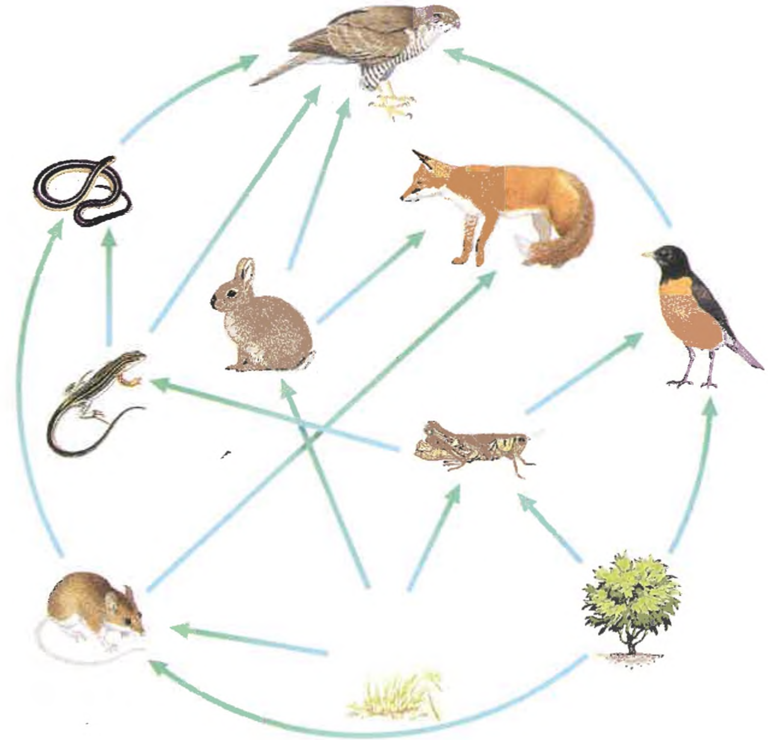
Whenever one organism eats another, molecules are metabolized and energy is transferred. As a result, energy flows through an ecosystem, moving from producers to consumers. One way to follow the pattern of energy flow is to group organisms in an ecosystem based on how they obtain energy. An organism's **trophic** (TROH-fik) **level** indicates the organism's position in the sequence of energy transfers, as shown in Figure 22-2. For example, all producers belong to the first trophic level. Herbivores belong to the second trophic level, and the predators of herbivores belong to the third level. Most ecosystems contain only three or four trophic levels.

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 on the chain may be a carnivorous snake, which kills and eats the mouse. A hawk then may eat the snake.

FIGURE 22-3

This food web shows how some organisms in an ecosystem might relate to each other. Because a large carnivore may be at the top of several food chains, it is often more helpful for ecologists to diagram as many feeding relationships as possible in an ecosystem. You can imagine how complicated this food web would be if it were possible to catalog every species present in an ecosystem.



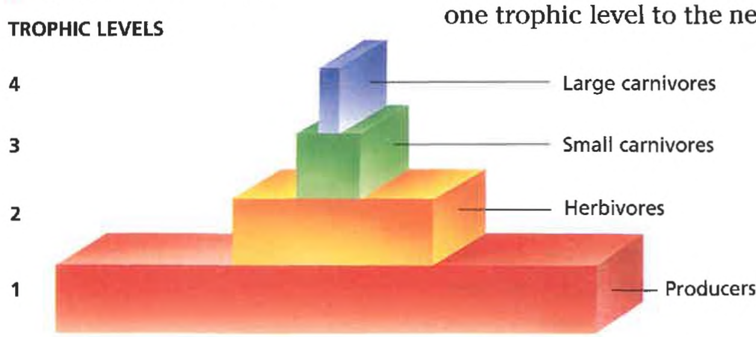
The feeding relationships in an ecosystem are usually too complex to be represented by a single food chain. Many consumers eat more than one type of food. In addition, more than one species of consumer may feed on the same organism. Many food chains interlink, and a diagram of the feeding relationships among all the organisms in an ecosystem would resemble a web. For this reason, the interrelated food chains in an ecosystem are called a **food web.** Figure 22-3 shows a simplified food web.

Quantity of Energy Transfers

Roughly 10 percent of the total energy consumed in one trophic level is incorporated into the organisms in the next level. The ability to maintain a constant body temperature, the ability to move, and a high reproductive rate are functions that require a lot of energy. The kinds of organisms that have those characteristics will transfer less energy to the next trophic level than organisms that do not. For example, grass transfers more energy to a moose than the moose transfers to a wolf. The measured values for energy transfer from one trophic level to the next can range from 20 percent to less than 1 percent. In a recent study of wolves and moose on Isle Royale, Michigan, ecologists found that only 1.3 percent of the total energy consumed by the moose on the island was transferred to the wolves through the wolves' predation on the moose. Figure 22-4 represents the rate at which each trophic level in an ecosystem stores energy as

FIGURE 22-4

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 pyramidal in shape.



organic material. The pyramid shape of the diagram represents the low percentage of energy transfer from one trophic level to another.

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.

To understand this idea better, consider what happens when a deer eats 1,000 kcal of leaves. About 350 kcal are eliminated as urine, dung, and other wastes. Another 480 kcal are lost as heat. Only about 170 kcal are actually stored as organic matter, mostly as fat. Producers use and transfer energy in a similar way. A plant stores only about 1–5 percent of the solar energy that it converts to sugar as organic material. The rest is reflected off the plant, used in its life processes, or lost in the form of heat.

Short Food Chains

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 all the organisms at the highest trophic level to support additional levels.

Organisms belonging to the lowest trophic level are usually much more abundant than organisms belonging to the highest level. If you go on a safari in Kenya or Tanzania, for example, you will see about 1,000 zebras, gazelles, wildebeest, and other herbivores for every lion or leopard you see, and there are far more grasses, trees, and shrubs than there are herbivores. Higher trophic levels contain less energy, and, as a consequence, they can support fewer individuals.

SECTION 22-1 REVIEW

1. **Why are autotrophs essential components of an ecosystem?**

2. **What role do decomposers play in an ecosystem? Why is this role important?**

3. **How does a food chain differ from a food web?**

4. **Give two reasons for the low rate of energy transfer within ecosystems.**

5. **Explain why the same area of land can support more herbivores than carnivores.**

6. **CRITICAL THINKING** **Suppose you remove the rabbits, grasshoppers, birds, and mice (the herbivores) from a food web that also includes grass, mushrooms, lizards, and hawks. Which organisms would be affected and how?**

SECTION

22-2

OBJECTIVES

▲ Define *biogeochemical cycle.*

● Trace the steps of the water cycle.

■ Summarize the major steps in the nitrogen cycle.

◆ Describe the steps of the carbon cycle.

ECOSYSTEM RECYCLING

While energy flows through an ecosystem, water and minerals, such as carbon, nitrogen, calcium, and phosphorus, are recycled and reused. Each substance travels through a ***biogeochemical*** *(BIE-oh-GEE-oh-KEM-i-kuhl)* ***cycle,*** *moving from the abiotic portion of the environment, such as the atmosphere, into living things, and back again.*

THE WATER CYCLE

Water is crucial to life. Cells contain 70 percent to 90 percent water, and water provides the aqueous 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 the oceans contain a substantial percentage of the 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

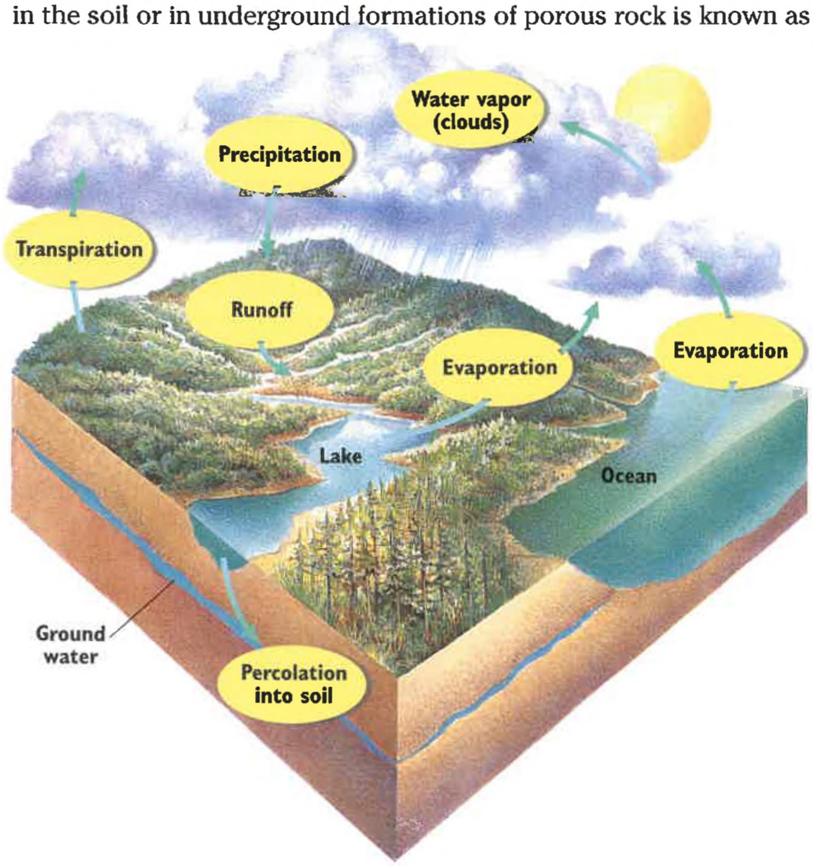


FIGURE 22-5

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 into the ground water. Follow the pathways of the water cycle in the figure.

ground water. The movement of water between these various reservoirs, known as the **water cycle,** is illustrated in Figure 22-5.

Three important processes in the water cycle are evaporation, transpiration, and precipitation. Evaporation adds water as vapor to the atmosphere. Heat causes water to evaporate from the oceans and other bodies of water, from the soil, and from the bodies of living things. At least 90 percent of the water that evaporates from terrestrial ecosystems passes through plants in a process called **transpiration.** In transpiration, plants take in water through their roots, and they release water and take in carbon dioxide through the stomata in their leaves. Animals also participate in the water cycle, but their impact is less significant than that of plants. 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

Together, photosynthesis and cellular respiration form the basis of the **carbon cycle,** which is illustrated in Figure 22-6. During 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

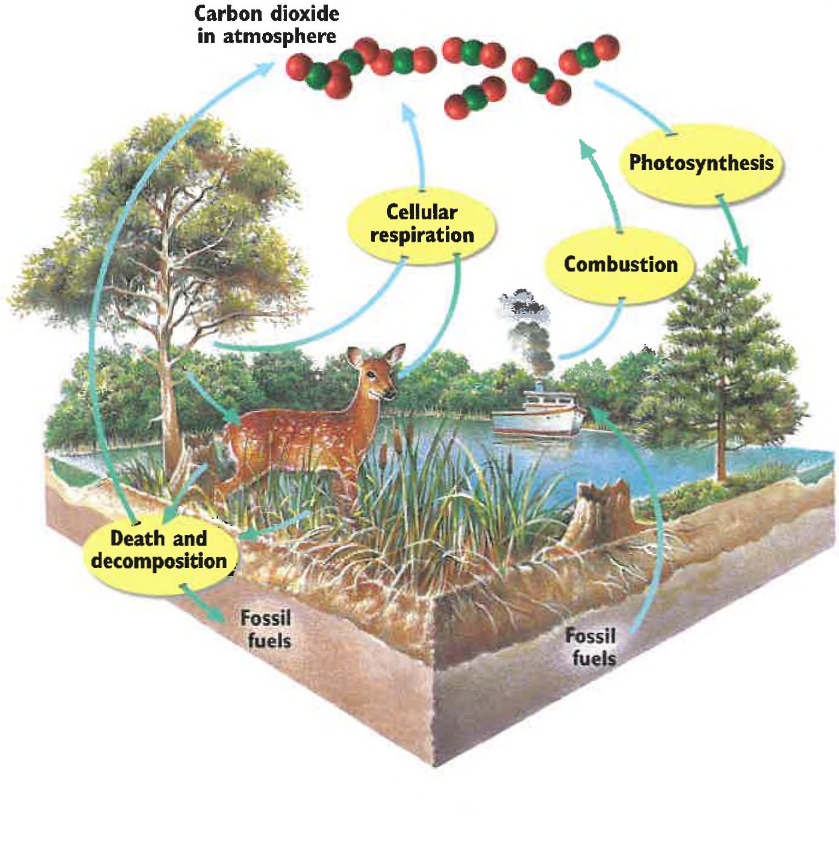


FIGURE 22-6

Carbon exists in the atmosphere in the form of carbon dioxide. Cellular respiration, combustion, and decomposition of organic matter are the three major sources of carbon dioxide. By burning large amounts of fossil fuels, humans are increasing the amount of carbon dioxide in the atmosphere.

Quick Lab

Modeling Ground Water

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 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?

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.

Human Influence on the Carbon Cycle

In the last 150 years, the concentration of carbon dioxide in the atmosphere has risen nearly 30 percent. Almost half of this increase has occurred in the last 40 years. Human activities are responsible for the increase. 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 organic molecules. Burning releases the energy in these molecules, but it also releases carbon dioxide. Carbon dioxide is also added to the atmosphere by the burning of vegetation. Today large areas of tropical rain forest are being burned to create farmland and pasture for cattle. The burning of vegetation adds carbon dioxide to the atmosphere, and the destruction of vegetation removes plants that could have absorbed carbon dioxide from the atmosphere through photosynthesis.

THE NITROGEN CYCLE

All organisms need nitrogen to make proteins and nucleic acids. The complex pathway that nitrogen follows within an ecosystem is called the **nitrogen cycle.** Consider how nitrogen cycles within the terrestrial ecosystem shown in Figure 22-7. Nitrogen gas, N_2, makes up about 78 percent of the atmosphere, so it might seem that nitrogen would be readily available for living things. However, shortages

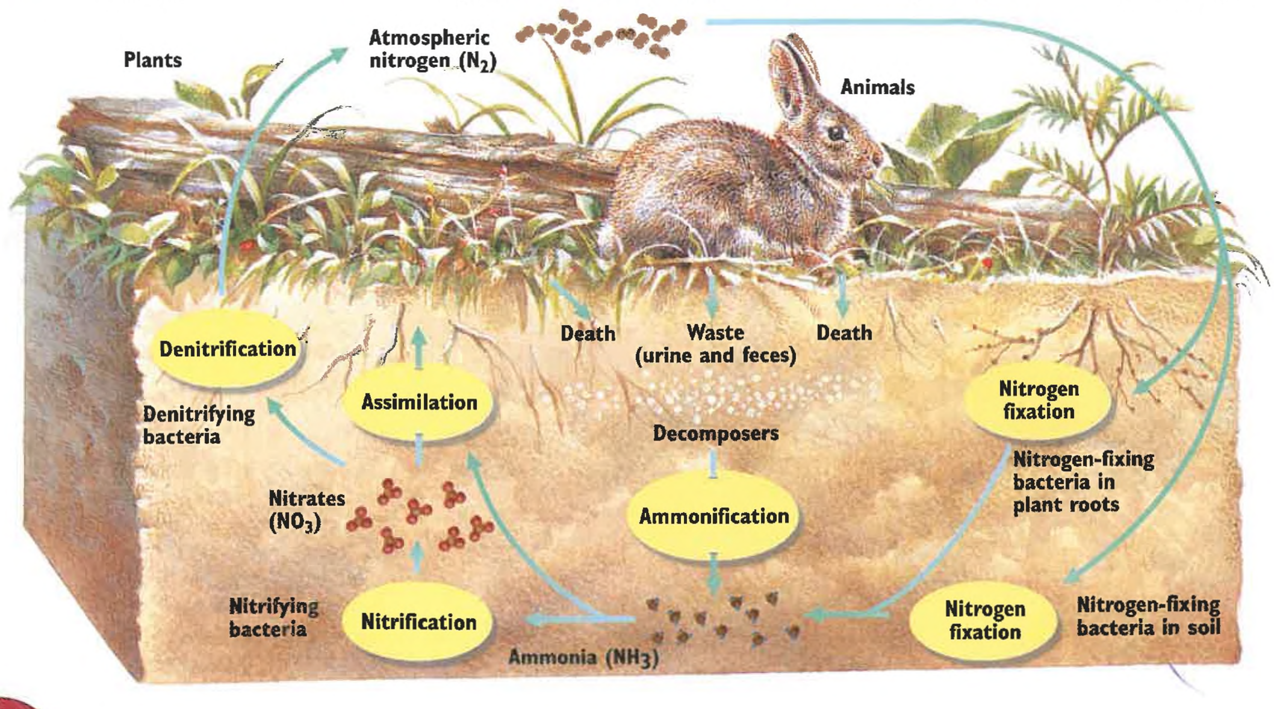


FIGURE 22-7

This figure shows the cycling of nitrogen within an ecosystem. Bacteria are responsible for many of the steps in the nitrogen cycle, including the conversion of atmospheric nitrogen into ammonia. Nitrogen-fixing bacteria live in the soil or in the roots of plants. Plants take up the ammonia produced by the bacteria. Animals get nitrogen by eating plants or other animals.

of nitrogen often limit the productivity of plants—and therefore the productivity of ecosystems. Most plants can use nitrogen only in the form of nitrate. The process of converting nitrogen gas to nitrate is called **nitrogen fixation.** Organisms rely on the actions of bacteria that are able to transform nitrogen gas into a usable form. Separate groups of **nitrogen-fixing bacteria** convert nitrogen gas into ammonia, then nitrite, and then nitrate, which plants can use.

Nitrogen-fixing bacteria live in the soil and in the roots of some kinds of plants, such as beans, peas, clover, and alfalfa. These plants have evolved a complex mutualistic relationship with nitrogen-fixing bacteria. The plant provides the bacteria with a home—airtight swellings on its roots—and supplies them with carbohydrates. In exchange, the bacteria produce usable nitrogen for the plant. Excess nitrogen produced by the bacteria is released into the soil.

Recycling Nitrogen

The bodies of dead organisms contain nitrogen, mainly in proteins and nucleic acids. Urine and dung also contain nitrogen. Decomposers break down the corpses and wastes of organisms and release the nitrogen they contain as ammonia. This process is known as **ammonification** (ah-MAHN-i-fi-KAY-shuhn). Through ammonification, nitrogen that would otherwise be lost is reintroduced into the ecosystem.

Bacteria in the soil take up ammonia and oxidize it into nitrites, NO_2^-, and nitrates, NO_3^-. This process, called **nitrification** (NIE-tri-fi-KAY-shuhn), is carried out by bacteria. 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 back 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.

SECTION 22-2 REVIEW

1. **Describe the biogeochemical cycle.**
2. **Where do nitrogen-fixing bacteria live? What crucial function do they perform?**
3. **Describe the role of decomposers in the nitrogen cycle.**
4. **How has the burning of fossil fuels affected the carbon cycle?**
5. **Through what process does most water vapor enter the atmosphere? Explain the process.**
6. **CRITICAL THINKING Explain two ways that the burning of vegetation affects carbon dioxide levels in the atmosphere. How do you think the removal of vegetation affects oxygen levels in the atmosphere?**

SECTION

22-3

OBJECTIVES

▲ Describe the differences between tundra and taiga biomes.

● Contrast temperate grassland with savanna.

■ Describe three water-conservation adaptations of desert organisms.

◆ Compare tropical rain forests with temperate deciduous forests.

TERRESTRIAL ECOSYSTEMS

Biomes *(BIE-ohmz) are very large terrestrial ecosystems that contain a number of smaller but related ecosystems within them. A certain biome may exist in more than one location on Earth, but similar biomes have similar climates and tend to have inhabitants with similar adaptations.*

THE SEVEN MAJOR BIOMES

Biomes are distinguished by the presence of characteristic plants and animals, but they are commonly identified by their dominant plant life. For example, hardwood trees, such as beeches and maples, are the dominant form of plant life in the deciduous forest biome. Most ecologists recognize seven major biomes, shown on the map in Figure 22-8, and several minor biomes. In this section, you will learn about the characteristics of the seven major biomes: tundra, taiga, temperate deciduous forest, temperate grassland, desert, savanna, and tropical rain forest.

Because abiotic factors change gradually over a landscape, biomes seldom have distinct boundaries. As climate varies over the Earth's surface, for example, deserts tend to gradually change into grasslands, tundra into taiga, and so on. Figure 22-8 shows how the

FIGURE 22-8

The seven biomes cover most of the Earth's land surface. Antarctica is not shown because it has no biomes.

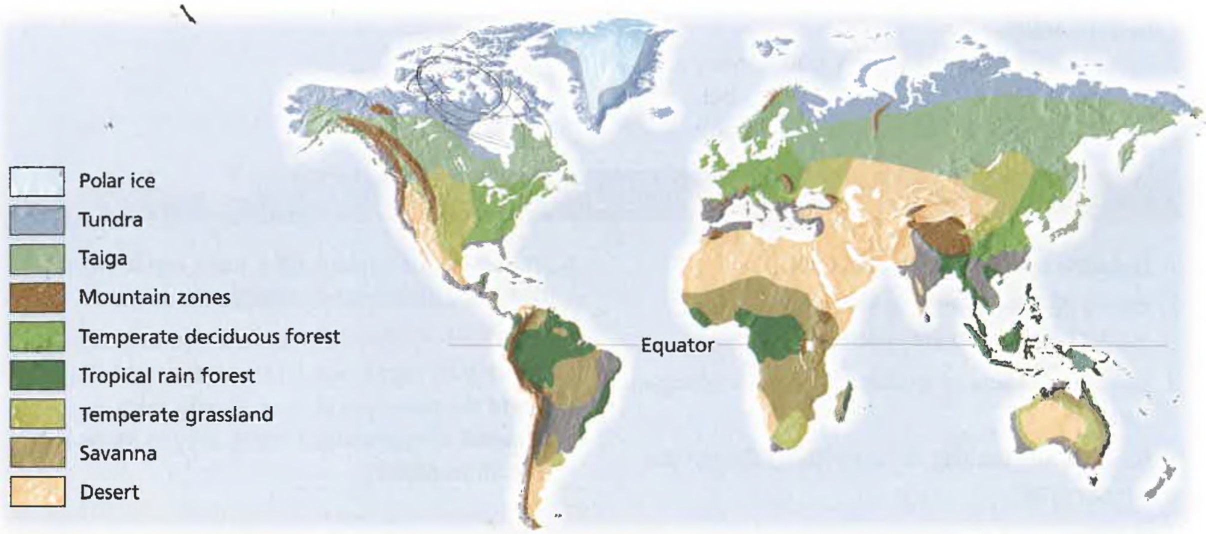


TABLE 22-1 Characteristics of the Major Biomes

Biome	Average yearly temperature range	Average yearly precipitation	Soil	Vegetation
Tundra	−26°C to 12°C	<25 cm	moist, thin topsoil over permafrost; nutrient-poor; slightly acidic	mosses, lichens, dwarf woody plants
Taiga	−10°C to 14°C	35–75 cm	low in nutrients; highly acidic	needle-leaved evergreen trees
Temperate deciduous forest	6°C to 28°C	75–125 cm	moist; moderate nutrient levels	broad-leaved trees and shrubs
Temperate grassland	0°C to 25°C	25–75 cm	deep layer of topsoil; very rich in nutrients	dense, tall grasses in moist areas; short clumped grasses in drier areas
Desert	7°C to 38°C	<25 cm	dry, often sandy; nutrient-poor	succulent plants and scattered grasses
Savanna	16°C to 34°C	75–150 cm	dry, thin topsoil; porous, low in nutrients	tall grasses, scattered trees
Tropical rain forest	20°C to 34°C	200–400 cm	moist, thin topsoil; low in nutrients	broad-leaved ever-green trees and shrubs

seven major biomes are distributed over the Earth. The figure also shows the areas that cannot be classified into one of the seven major biomes. Because climate varies with elevation, mountains contain a variety of communities and do not belong to any one biome. Table 22-1 describes the major biomes and lists their average annual temperature and rainfall.

TUNDRA

The **tundra** (TUHN-druh) is a cold and largely treeless biome that forms a continuous belt across northern North America, Europe, and Asia. It is the largest and northernmost biome, covering about one-fifth of the world's land surface. **Permafrost,** a permanently frozen layer of soil under the surface, characterizes the tundra. Even the surface soil above the permafrost remains frozen for all but about eight weeks of the year. Figure 22-9 shows some of the plants of the tundra.

Trees do not usually grow in the tundra because the winters are long and bitterly cold and because permafrost prevents their roots from penetrating far into the soil. The

FIGURE 22-9

This photograph shows that the tundra is usually bleak and uniform in appearance, although there may be bright patches of color in the summer season.

FIGURE 22-10

Organisms of the taiga are adapted for dry, cold conditions and a reduced availability of food in the winter season. The conifers have needles, which are leaf adaptations to conserve water.

tundra receives little precipitation and has a very short growing season of about two months. Cold temperatures retard decay, so the soil is often low in nutrients. For these reasons, tundra plants are usually small and grow slowly. Grasses, sedges, and mosses are common.

Animals that inhabit the tundra include caribou, musk oxen, snowy owls, arctic foxes, lemmings, and snowshoe hares. In the brief summer, the frozen soil thaws, creating a patchwork of ponds and bogs. Swarms of mosquitoes and black flies appear, and ducks, geese, and predatory birds arrive in great numbers to feed.

TAIGA

South of the tundra is the **taiga** (TIE-guh), a forested biome dominated by cone-bearing evergreen trees, such as pines, firs, hemlock, and spruce. Taiga stretches across large areas of northern Europe, Asia, and North America. During the long winter, snow covers and insulates the ground, protecting tree roots against freezing.

Plants living in the taiga are adapted for long and cold winters, short summers, and nutrient-poor soil. On the cone-bearing evergreen trees, called conifers, the waxy needles remain all winter long. The shape of the needle is a leaf adaptation that reduces water loss. The stomata of conifers are partially enclosed in the needle, which helps the tree conserve water. Typical mammals of this biome include moose, bears, wolves, and lynx. Some animals stay in the forest year-round, while others migrate to warmer climates in the fall and return in the spring. Many species hibernate six to eight months of the year. Figure 22-10 shows a representative area of taiga.

Word Roots and Origins

taiga

from the Russian word *taiga*, meaning "a transitional plant community"

TEMPERATE DECIDUOUS FORESTS

Temperate deciduous forests are characterized by trees that lose all of their leaves in the fall. Deciduous forests stretch across eastern North America, much of Europe, and parts of Asia and the Southern Hemisphere. These regions have pronounced seasons, with precipitation evenly distributed throughout the year. Compared with taiga, temperate deciduous forests have warmer winters and longer summers, and they receive more precipitation. Deciduous trees have broad, thin leaves with a large surface area that permits maximum

FIGURE 22-11

A temperate deciduous forest is characterized by trees that lose their leaves in the winter. This adaptation to conserve water also creates an energy loss for the tree. The tree will never recover the energy that went into its leaf formation, but the decaying leaves on the forest floor will add nutrients to the soil. Temperate deciduous forests are inhabited by a variety of animals, such as cardinals and white-tailed deer.

light absorption. Familiar deciduous trees include the birch, beech, maple, oak, hickory, sycamore, elm, willow, and cottonwood. White-tailed deer, foxes, raccoons, and squirrels are typical mammals of the temperate deciduous forests. Large areas of temperate deciduous forest in the United States, Europe, and Asia have been cut for timber or cleared to make way for farms, towns, and cities. Figure 22-11 shows a stand of trees in a temperate deciduous forest.

TEMPERATE GRASSLANDS

Temperate grasslands are, as the name suggests, dominated by grasses. Temperate grasslands usually form in the interior of continents, at about the same latitude as temperate deciduous forests. However, rainfall patterns make these areas too dry to support trees. This biome once covered large areas of North America, Asia, Europe, Australia, and South America. Grasslands are known by different names in different parts of the world: *prairie* in North America, *steppes* in Asia, *pampas* in South America, and *veldt* in southern Africa.

Temperate grasslands have rich, fertile soil. In areas that have remained relatively undisturbed by humans, grasslands support large herds of grazing mammals, such as the bison shown in Figure 22-12. Grass can survive continuous grazing by animals and occasional fires that sweep across the area because the actively growing part of the plant is at or below the ground, rather than at the tip of the stem. Because grasslands have such rich soil, much of the world's temperate grassland has been transformed into farmland for growing crops such as wheat and corn. Only fragments of undisturbed prairie remain in the United States.

FIGURE 22-12

Temperate grasslands once covered a large portion of the United States and supported huge herds of herbivores, such as the bison shown below. Today, several conservation organizations are actively attempting to preserve this valuable, endangered biome.

FIGURE 22-13

A desert biome may appear lifeless at first glance. But on closer inspection, the desert reveals many living things. All of the organisms of the desert biome are adapted to dry, often hot conditions and are adapted for conserving energy. The saguaro cactus shown stores water from the infrequent rains of the desert.

DESERTS

Deserts are areas that receive an average of less than 25 cm (9.9 in.) of rainfall per year. Large parts of North Africa, central Australia, southwestern North America, and eastern Asia are desert. Contrary to popular belief, deserts are not hot all the time. So-called cold deserts, such as the Great Basin in the western United States and the Gobi in eastern Asia, are hot in summer but cold in winter. Even in hot deserts, temperatures may fall by as much as 30°C (54°F) at night because the dry air is a poor insulator, allowing the heat that builds up during the day to escape.

Desert vegetation is often sparse and consists mainly of plants that have adapted to the dry climate. The leaves of the creosote bush of the United States and Mexico, for example, have a waxy coating that reduces evaporation. To limit water loss through transpiration, some desert plants open their stomata only at night. The saguaro cactus, which is found in southern Arizona and southeastern California, as well as in northern Mexico, has an expandable body, an adaptation that allows it to store water. A single saguaro can hold about 1,000 kg (2,200 lb) of water. The saguaro, as seen in Figure 22-13, has evolved sharp protective spines, a leaf adaptation that protects the plant from thirsty herbivores.

Desert animals must conserve water just as the plants do. Many animals avoid the heat of the day by hiding in small spots of shade or by burrowing into the ground. Others, such as kit foxes and some kinds of lizards and snakes, are active only at night, when loss of water to evaporation is low.

FIGURE 22-14

The savanna biome is an area rich in wildlife, where great herds of large herbivores exist. Because of the large number of herbivores, this area also supports many large carnivores. The climate of a savanna experiences only two seasons—wet and dry.

SAVANNAS

Savannas (suh-VAN-uhz) are tropical or subtropical grasslands with scattered trees and shrubs. The savannas of Africa are the best known, but this biome also occurs in South America and Australia. Savannas receive more rainfall than deserts, but less than tropical rain forests. Alternating wet and dry seasons characterize savannas. Like temperate grasslands, savannas support large numbers of herbivores, such as zebras, wildebeest, giraffes, and gazelles, as shown in Figure 22-14. Large carnivores, such as lions, leopards, and cheetahs, feed on these herbivores.

Because most of the rain falls during the wet season, the plants and animals of the savanna must be able to deal with prolonged periods of drought. Some trees of the savanna shed their leaves during the dry season to conserve water, and the above-ground parts of grasses often die during the dry season and regenerate after a period of rain.

TROPICAL RAIN FORESTS

Tropical rain forests are characterized by tall trees like those shown in Figure 22-15. Tropical rain forests are found near the equator in Asia, Africa, South America, and Central America. The stable, year-round growing season and abundant rainfall combine to make the tropical rain forest the most productive biome.

Competition for light is intense in the tropical rain forest. Most of the plants are trees, and some have evolved to grow as tall as 50 to 60 m (164 to 197 ft). The treetops form a continuous layer, called the **canopy,** that shades the forest floor. Though you may think of the tropical rain forest as an impenetrable jungle, much of the forest floor is relatively free of vegetation because so little sunlight reaches the ground. The very dense growth known as jungle is found along riverbanks and in disrupted areas where sunlight can reach the forest floor. Small plants called **epiphytes,** as shown in Figure 22-15a, which would not get enough light on the forest floor, often live on the branches of tall trees. These plants, which include mosses and orchids, use other organisms as support, but they are not parasitic because they make their own food.

Tropical rain forests have the highest species richness of all the biomes. One hectare of tropical rain forest (about the size of two football fields) may contain as many as 300 species of trees. An area of temperate deciduous forest of the same size, by contrast, would probably contain fewer than 10 species of trees. Animal life is also very diverse in the tropical rain forest. The sloth, pictured in Figure 22-15b, is a rain forest mammal. Colorful birds, such as parrots and toucans, many kinds of monkeys, and a variety of snakes and lizards are among the vertebrate inhabitants of this biome. The variety of insects is particularly diverse in tropical rain forests. There may be more than 8 million species of tree-dwelling beetles in the tropical rain forest biome alone. Overall, tropical rain forests probably contain about one-fifth of the world's known species.

FIGURE 22-15

Animal life is as diverse as plant life in the rain forest, as reflected by the epiphyte, shown in (a), and the three-toed sloth, a tree dweller of the rain forest, shown in (b).

(a)

(b)

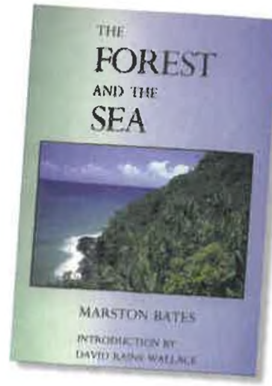
SECTION 22-3 REVIEW

1. Why would it be unusual to find a tree in the tundra?
2. What two similarities are shared by temperate grassland and savanna?
3. Describe two adaptations of the saguaro cactus for water conservation.
4. List at least one animal that lives in each of these biomes: desert, temperate grassland, and tundra.
5. Why do many animals in the tropical rain forest live in trees?
6. CRITICAL THINKING Explain the benefits deciduous trees gain from shedding their leaves in the fall. Describe some possible disadvantages of shedding leaves.

Literature & Life

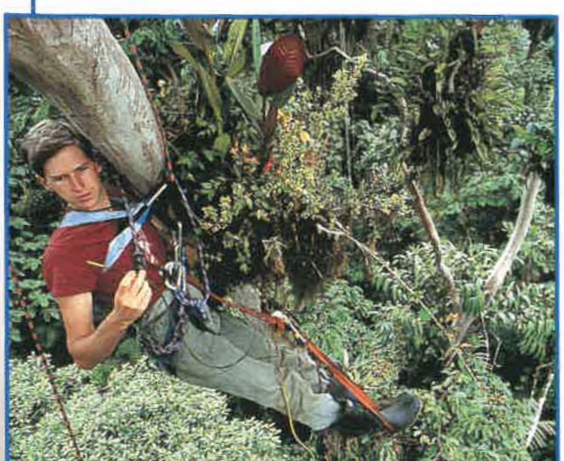
The Forest and the Sea

The following account is from *The Forest and the Sea,* by Marston Bates.



When a botanist visited the South American forest station where Marston Bates was working, Bates and the visitor climbed up onto a platform high in the forest canopy. Mosquitoes began buzzing about them.

In the course of our mosquito studies we had found that each different species had its characteristic flight habits. Some kinds were found only near the ground, others only high in the trees; some that were most common high in the trees in the morning or afternoon would come down near the ground during the midday hours, showing a sort of daily vertical migration.



While I was explaining this to my friend, it struck me, that this is just the way animals act in the sea. Most life is near the top, because that is where the sunlight strikes and everything below depends on this surface. Life in both the forest and the sea is distributed in horizontal layers.

The analogy, once thought of, was easily developed. The vocabulary for life in the sea could be transferred to the forest. In the treetops we were in what marine students call the pelagic zone—the zone of active photosynthesis, where sunlight provides the energy to keep the whole complicated biological community going. Below, we had been in the benthos, the bottom zone, where organisms live entirely on secondhand materials that drift down from above—on fallen leaves, on fallen fruits, on roots and logs. Only a few special kinds of green plants were able to grow in the rather dim light that reached the forest floor.

My mosquitoes acted in some ways like the microscopic floating life of the sea, the plankton. Each species among the plankton organisms has a characteristic vertical distribution: some living only near the surface, others only at considerable depths, and so forth. The plankton organisms in general show a daily vertical migration, coming to the surface at night and sinking during the day: a migration to which my mosquitoes were only a feeble counterpart. But insects on land are only partially analogous with the plankton of the sea. A major portion of the plankton consists of microscopic plants, busy using the energy of the sun and the dissolved carbon dioxide of the water to build up starch and thus provide the basis for all the rest of the life of the sea. These microscopic plants would correspond not to the insects of the forest, but to the leaves of the trees.

The forest insects would correspond only to the animal component of the plankton: to the copepods and tiny shrimp and larval fish which live directly on the plants or on each other at the very beginning of the endless chain of who eats whom in the biological community.

Reading for Meaning

Bates compared living forms of the forest with those of the sea. Why does he say that mosquitoes and plankton are "only partly analogous"?

Read Further

In *The Forest and the Sea,* Bates presents observations based on his field studies in two very different biomes. What advantages might be found in comparing seemingly dissimilar organisms?

AQUATIC ECOSYSTEMS

As terrestrial organisms, we tend to focus on the other land-dwelling organisms we see around us. But life may have arisen in the sea and only recently (in geological terms) colonized the land. Water covers about three-fourths of Earth and is home to a variety of organisms. In this section we will look at some of the inhabitants of aquatic ecosystems.

SECTION

22-4

OBJECTIVES

▲ Contrast the aphotic and photic zones in the ocean.

● Describe the differences between the neritic zone and the oceanic zone.

■ Explain how organisms near deep-sea vents obtain energy.

◆ Contrast eutrophic lakes with oligotrophic lakes.

OCEAN ZONES

The ocean covers about 70 percent of Earth's surface and has an average depth of 3.7 km (2.3 mi). The deepest parts of the ocean are about 11 km (6.8 mi) deep. The water contains about 3 percent salt, mostly sodium chloride, a factor that profoundly affects the biology of the organisms that live there. Another important variable affecting marine organisms is the availability of light. Because water absorbs light, sunlight penetrates only the upper few hundred meters of the ocean. The **photic** (FOH-tik) **zone** is the part of the ocean that receives sunlight. The rest of the ocean falls within the **aphotic** (AY-FOH-tik) **zone,** the cold and dark depths where sunlight cannot penetrate. Photosynthesis cannot occur in the aphotic zone because of the lack of sunlight.

Ecologists recognize three zones extending out from land, as illustrated in Figure 22-16. Along ocean shores, the tides produce a rhythmic rise and fall of the water level in an area called the **intertidal zone.** Farther out is the **neritic** (nee-RI-tik) **zone,** which extends

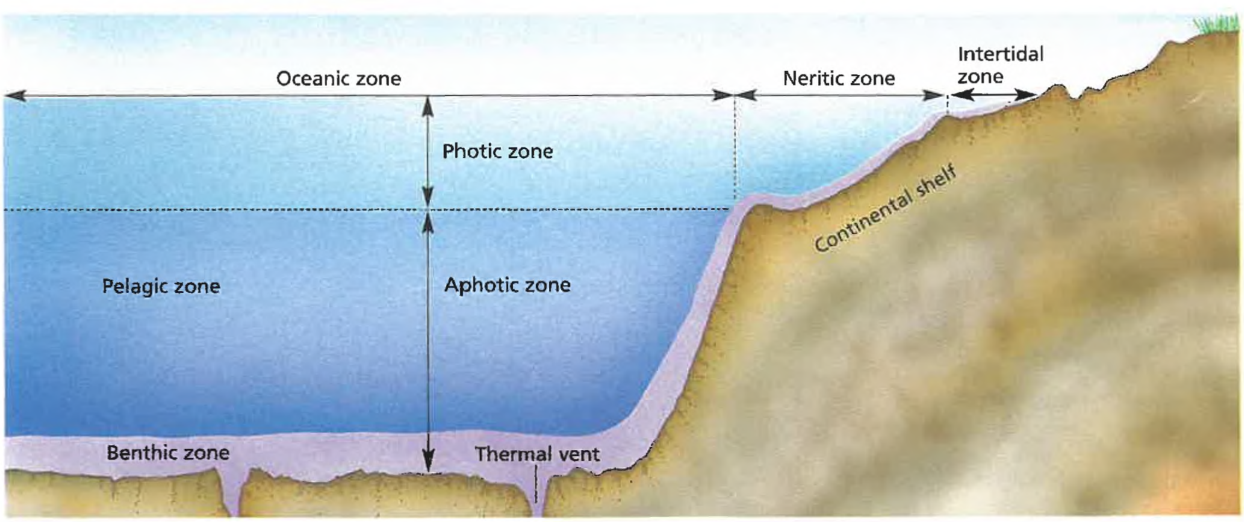


FIGURE 22-16

This diagram shows the various zones of the ocean. The neritic zone generally extends from the intertidal zone to the point where water depth is about 180 m (590 ft). The photic zone varies in depth, depending on how far light penetrates into the water.

over the continental shelf. The water in the neritic zone is relatively shallow (no more than a few hundred feet deep). Beyond the continental shelf is the **oceanic zone,** which is the deep water of the open sea. The neritic and oceanic zones are further divided. The open ocean is known as the **pelagic** (pi-LA-jik) **zone,** while the ocean bottom is known as the **benthic zone.**

FIGURE 22-17

The intertidal zone shown here is similar to intertidal zones all over the planet. Some are artificially created by the construction of rocky protective bulkheads along former stretches of beach. An open beach is part of the intertidal zone, but it is usually distinguished from the rocky intertidal zones and not as rich in species as rocky intertidal zones.

The Intertidal Zone

Organisms in this zone are adapted to periodic exposure to air during low tide. Crabs avoid dehydration by burrowing into the sand or mud. Clams, mussels, and oysters retreat into their shells at low tide. Organisms living in the intertidal zone must be able to withstand the force of crashing waves. Sea anemones cling to rocks with a muscular disk, and sea stars use tube feet to adhere to surfaces. Figure 22-17 shows some of the organisms living in the intertidal zone of the California coast.

The Neritic Zone

The neritic zone is the most productive zone in the ocean, supporting more species and numbers of organisms than any other zone. The water throughout most of the neritic zone is shallow enough for photosynthesis to occur. Strong currents called upwellings carry nutrients from the ocean bottom and mix them with nutrients contained in runoff from land. These waters are rich in **plankton,** communities of small organisms that drift with the ocean currents. Plankton is consumed by many larger organisms. Numerous fishes, squid, sea turtles, and other animals also live in these waters.

Coral reefs form in the neritic zone of tropical areas. Like tropical rain forests, coral reefs are very productive and rich in species. A coral reef is built over a long time by coral animals. They construct external skeletons of a hard chemical compound called calcium carbonate. As the animals grow and die, the skeletons accumulate over time to form a reef, as shown in Figure 22-18, that is home to many species of fishes, crustaceans, mollusks, and other animals. Some species of coral have a mutualistic relationship with photosynthetic protists, from which they receive food.

internetconnect

SCILINKS NSTA

TOPIC: Aquatic ecosystems
GO TO: www.scilinks.org
KEYWORD: HM432

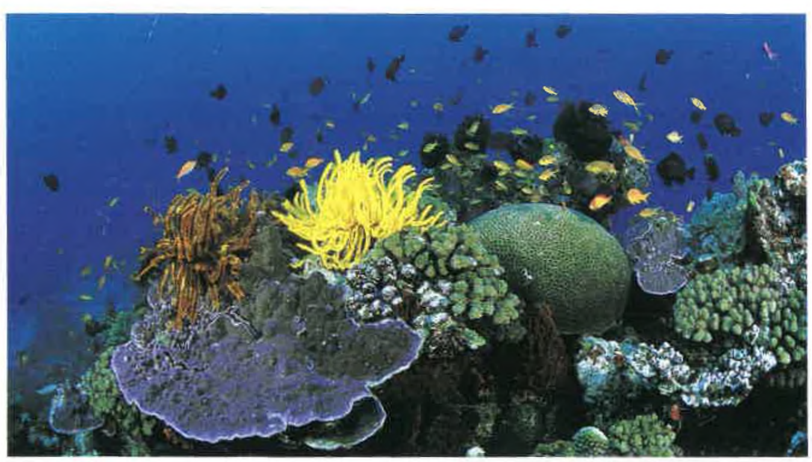


FIGURE 22-18

Coral reefs, such as the one pictured here, are among the most diverse ecosystems on Earth. Coral reefs are built from the skeletal remains of tiny marine animals and are continually growing just below the surface of warm sunlit seas.

The Oceanic Zone

The oceanic zone contains fewer species than the neritic zone. Even in photic areas, nutrient levels are too low to support as much life. Although the productivity per square meter of open ocean is very low because the ocean covers such a vast area, the total productivity of the oceanic zone is high. About half of the photosynthesis that occurs on Earth takes place in the oceanic zone. The producers of the upper parts of the oceanic zone are protists and bacteria in the plankton. Animals living in the oceanic zone include fishes, mammals such as whales, and many invertebrates.

In the aphotic zone, animals feed primarily on sinking plankton and dead organisms. Organisms living deep in the ocean must cope with near-freezing temperature and crushing pressure. Deep-sea organisms, like the squid shown in Figure 22-19, have slow metabolic rates and reduced skeletal systems. Fishes in these depths have large jaws and teeth and expandable stomachs that can accommodate the rare prey that they can catch.

In the 1970s, scientists found diverse communities living near volcanic vents 2,500 m (8,200 ft) below the surface. These vents release water that is rich in minerals and often exceeds 750°C. Chemosynthetic bacteria that use energy contained in hydrogen sulfide (H_2S) are the producers for this ecosystem. An assortment of unique clams, crabs, and worms feed on these bacteria. Clamworms living near thermal vents have lost their digestive system over evolutionary time and receive all of their food directly from chemosynthetic bacteria living in their bodies.

FIGURE 22-19

Organisms in the deep sea have many adaptations to their environment. The squid *Vampyroteuthis* sp., in the photograph is adapted to eating a large quantity of food at once because prey is hard to find.

Estuaries

An **estuary** (ES-tyoo-eree) occurs where freshwater rivers and streams flow into the sea. Examples of estuary communities include bays, mud flats, and salt marshes. The shallow water ensures plenty of light, and rivers deposit large amounts of mineral nutrients. However, the interaction between fresh water and salt water causes great variation in temperature and salinity. In addition, like the intertidal zone, much of the ground surface of an estuary is exposed during low tide. Inhabitants of estuaries are adapted for frequent change. For example, some kinds of mangrove trees have special glands on their leaves that eliminate excess salt water taken up by the roots. Soft-shell clams lie buried in mud with only their long siphons protruding above the surface. The siphon filters plankton from the salt water at high tide and detects predators at low tide, contracting whenever it senses danger. Figure 22-20 is an example of an estuary.

FIGURE 22-20

Estuaries are almost as species rich as tropical rain forests. The plant life is often uniform, but the bird and aquatic diversity is enormous. Estuaries are the ocean's nurseries. Many marine organisms hatch and spend their juvenile life stages in the estuary. The dense vegetation protects them from pounding wave action and gives them cover from predators. Estuaries are vital to marine animals that are used as food by people all over the world. Examples of food animals that begin life in estuaries are shrimp, mullet, redfish, and anchovies.

Word Roots and Origins

oligotrophic

from the Greek *oligos*, meaning "small," and the Greek *trophikos*, meaning "food"

FRESHWATER ZONES

Low levels of dissolved salts characterize freshwater ecosystems. The salt content of fresh water is about 0.005 percent. Examples of freshwater ecosystems include lakes, ponds, clear mountain streams, and slow sediment-rich rivers.

Lakes and Ponds

Ecologists divide lakes and ponds into two categories. **Eutrophic** (yoo-TRAH-fik) lakes are rich in organic matter and vegetation, making the waters relatively murky. The giant water lily pictured in Figure 22-21 is growing in a shallow eutrophic pond. **Oligotrophic** (AH-li-goh-TRAH-fik) **lakes** contain little organic matter. The water is much clearer, and the bottom is usually sandy or rocky. Fishes inhabit both eutrophic and oligotrophic lakes. Freshwater lakes and ponds also support mammals, such as the otter and muskrat, and birds, such as ducks and loons.

FIGURE 22-21

The Amazon water lily, *Victoria amazonica,* is adapted to life in shallow eutrophic ponds. As organic matter accumulates, the lake or pond will eventually fill in and disappear.

Rivers and Streams

A river is a body of water that flows down a gradient, or slope, toward its mouth. Water flows swiftly down steep gradients, and organisms are adapted to withstand powerful currents. For example, the larvae of caddis flies and the nymphs of mayflies cling to the rocky bottom, while brook trout and other fishes have evolved the strength to face upstream while feeding on drifting invertebrates. Slow-moving rivers and their backwaters are richer in nutrients and therefore support a greater diversity of life. Rooted plants and the fishes that feed on them are adapted to the weaker currents of slow-moving rivers.

SECTION 22-4 REVIEW

1. Distinguish between the photic and aphotic zones.
2. What are two sources of nutrients in the neritic zone?
3. What role do chemosynthetic bacteria play in deep-sea-vent ecosystems?
4. What is the main difference between oligotrophic and eutrophic lakes?
5. What might happen to organisms living in a fast-moving river if a dam is built on the river?
6. CRITICAL THINKING Estuaries serve as breeding sites and nurseries for thousands of species of marine animals. What characteristics of estuaries make them advantageous places for marine organisms to reproduce? What are some possible disadvantages?

CHAPTER 22 REVIEW

SUMMARY/VOCABULARY

22-1

- Autotrophic organisms are the primary producers. They manufacture carbohydrates using energy from the sun. Consumers obtain energy by eating other organisms.
- Gross primary productivity is the rate at which autotrophs capture energy. Net primary productivity is the rate at which primary producers make new biomass.
- Decomposers feed on dead bodies and wastes and release the nutrients they contain.
- A single pathway of energy transfer is called a food chain. A network showing all paths of energy transfer is called a food web.
- Food chains are short because a large amount of energy is used at each trophic level. There are fewer individuals and less biomass at higher trophic levels.

Vocabulary

biomass (415)	detritivore (416)	herbivore (416)	omnivore (416)
carnivore (416)	food chain (417)	net primary productivity (415)	producer (415)
chemosynthesis (415)	food web (418)		trophic level (417)
consumer (416)	gross primary productivity (415)		
decomposer (416)			

22-2

- Materials such as carbon, nitrogen, and water are cycled within ecosystems.
- The three key processes in the water cycle are evaporation, transpiration, and precipitation.
- Few organisms can use nitrogen directly from the environment. Nitrogen-fixing bacteria in the soil and in plant roots transform nitrogen gas into ammonia, which plants can use.
- Photosynthesis and cellular respiration are the two main processes of the carbon cycle. Cellular respiration adds carbon dioxide to the atmosphere, while photosynthesis removes it.
- By burning large amounts of fossil fuels and vegetation, humans are disrupting the carbon cycle. Many scientists think the rising level of carbon dioxide in the atmosphere will lead to global warming.

Vocabulary

ammonification (423)	denitrification (423)	nitrogen cycle (422)	transpiration (421)
biogeochemical cycle (420)	ground water (421)	nitrogen fixation (423)	water cycle (421)
carbon cycle (421)	nitrification (423)	nitrogen-fixing bacteria (423)	

22-3

- On land, there are seven major types of ecosystems, known as biomes.
- Tundra is a cold biome characterized by permafrost under the surface.
- Taiga is warmer than tundra and receives more precipitation. It is dominated by conifer forests.
- The trees in temperate deciduous forests shed all of their leaves in the fall.
- Temperate grasslands occur in areas with cold winters and hot summers. They are dominated by grasses and herds of grazing animals.
- Deserts receive less than 25 cm (9.9 in.) of precipitation per year. Their inhabitants have adaptations for water conservation.
- Savannas are tropical grasslands with alternating wet and dry seasons. They are dominated by herds of grazing animals.
- Tropical rain forests receive abundant rainfall and have a year-round growing season. They contain more species than any other biome.

Vocabulary

biome (424)	epiphyte (429)	taiga (426)	temperate grassland (427)
canopy (429)	permafrost (425)	temperate deciduous forest (426)	tropical rain forest (429)
desert (428)	savanna (428)		tundra (425)

22-4

- The photic zone in the ocean receives light, while the aphotic zone does not. There are three major zones in the ocean—the intertidal zone, the neritic zone, and the oceanic zone.
- In the intertidal zone, organisms must be able to tolerate drying and pounding by waves.
- The neritic zone receives nutrients from the bottom of the ocean and from land. It is the ocean's richest zone in terms of the number of species and individuals.
- Production in the oceanic zone is limited by a shortage of nutrients.
- Estuaries are very productive areas where rivers and streams flow into the sea.
- Oligotrophic lakes are clear and lacking in nutrients. Eutrophic lakes are rich in nutrients and are often murky.
- Rivers and streams are characterized by a gradient in elevation.

Vocabulary

aphotic zone (431)	eutrophic (434)	oceanic zone (432)	photic zone (431)
benthic zone (432)	intertidal zone (431)	oligotrophic lake (434)	plankton (432)
estuary (433)	neritic zone (431)	pelagic zone (432)	

REVIEW

Vocabulary

Explain the difference between the terms in each of the following pairs.

1. producer, decomposer
2. gross primary productivity, net primary productivity
3. tundra, taiga
4. nitrogen fixation, ammonification
5. biomass, biome

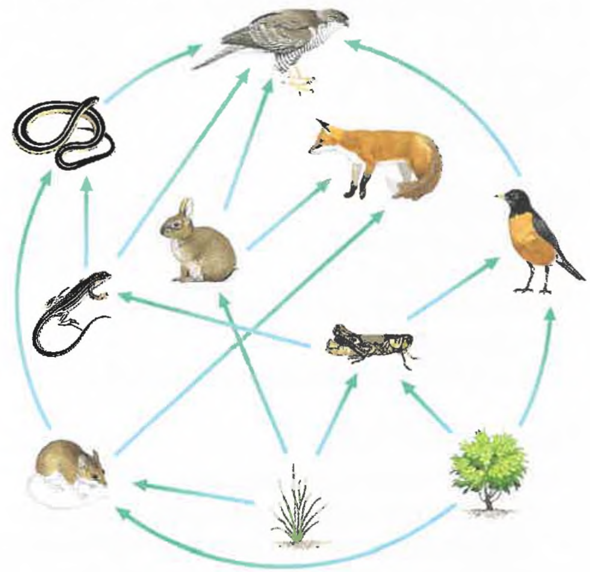
Multiple Choice

6. The major producers found in aquatic ecosystems are (a) photosynthetic protists (b) chemosynthetic bacteria (c) aquatic plants (d) heterotrophic protists.
7. Decomposers benefit an ecosystem by (a) manufacturing energy (b) returning nutrients to the soil (c) controlling the population (d) removing toxic substances.
8. Which of the following organisms from the African savanna would you expect to be the least abundant? (a) grass (b) lion (c) zebra (d) grasshopper
9. Which of the following is not true of the nitrogen cycle?
   (a) Plants absorb nitrogen gas directly from the atmosphere.
   (b) Bacteria convert nitrogen gas into ammonia.
   (c) Plants absorb ammonia from the soil.
   (d) Animals obtain nitrogen by eating other organisms.
10. The combustion of fossil fuels has increased atmospheric levels of (a) ammonia (b) nitrogen (c) CFCs (d) carbon dioxide.
11. One reason trees are unusual in the tundra is that (a) large herbivores eat them (b) there is not enough rainfall to support them (c) permafrost prevents root growth (d) grass and shrubs crowd them out.
12. Which of the following is not true of tropical rain forests?
    (a) They are found near the equator.
    (b) They have the highest species richness of any biome.
    (c) They show wide seasonal changes in temperature.
    (d) They are rapidly disappearing.
13. The neritic zone (a) receives nutrients from land (b) receives little sunlight (c) is exposed to the air by low tide (d) supports very few species.
14. Estuaries are among the most productive areas on Earth because (a) they are home to vast coniferous forests (b) they support great herds of herbivores (c) they have shallow, nutrient-laden water (d) they support many large predators.
15. Eutrophic lakes are (a) clear (b) murky (c) swift (d) small.

Short Answer

16. Explain the difference between a herbivore, a carnivore, and an omnivore. Give an example of each type of organism.

17. Examine the diagram of the food web below. How do you think the food web would be affected if the grass and the shrub were both eliminated? Explain your answer.



18. Why is a food web a more complete picture of the feeding relationships in an ecosystem than a food chain is?

19. Explain the difference between the terms *decomposer* and *detritivore.*

20. How does the transfer of energy in an ecosystem differ from the transfer of nutrients?

21. Describe the benefits nitrogen-fixing bacteria gain from the plants they inhabit. What does the plant receive from the bacteria?

22. Transpiration accounts for most of the water loss in plants. Explain why plants cannot shut their stomata for long periods of time.

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

24. **Unit 7—*Ecosystem Dynamics***

Write a report summarizing how artifical ecosystems are used to eliminate pollutants from wastewater. Find out what kinds of factories or plants use artificial ecosystems.

CRITICAL THINKING

1. Explain why farmers often grow alfalfa, clover, or beans in a field after they have grown corn.

2. Nitrogen, water, and carbon are recycled and reused within an ecosystem, but energy is not. Explain why energy cannot be recycled.

3. Thinning of the ozone layer may lead to reduced populations of photosynthetic plankton in the ocean. Explain how this would affect the carbon cycle.

4. This rare species of squid has several adaptations for living in very deep water. Explain some of the selective pressures that exist at great depths.

EXTENSION

1. Study an area near your home or school. Make a list of all the consumers, producers, and decomposers you observe. Draw a food web using the organisms you have observed.

2. Read "When Nature Goes Nuts" in *National Wildlife,* October–November 1999, on page 48. Choose three different animals mentioned in the article, and explain how each animal depends on the oak tree. What does the U.S. Forest Service blame for the decline of the oak?

3. Use library resources or an on-line database to research eutrophication of lakes. What is eutrophication? What causes eutrophication, and how does it affect the lake's inhabitants?

CHAPTER 22 INVESTIGATION

Constructing and Comparing Ecosystems

OBJECTIVES

- Observe the interaction of organisms in a closed ecosystem.
- Compare this ecosystem with others observed in nature.

PROCESS SKILLS

- observing
- recognizing relationships
- hypothesizing

MATERIALS

- large glass jar with lid for each ecosystem
- pond water or dechlorinated tap water
- gravel, rocks, and soil
- graph paper
- 8½ × 11 in. acetate sheets
- several colored pens for overhead transparencies

Ecosystem 1

- pinch of grass seeds
- pinch of clover seeds
- 10 mung-bean seeds
- 3 earthworms
- 4–6 isopods
- 6 mealworms
- 6 crickets

Ecosystem 2

- strands of *Anacharis, Fontinallis,* and foxtail
- duckweed
- *Chlamydomonas* culture
- black ram's horn snail
- 4 guppies or platys

Ecosystem 3

- small, clear glass container for water environment
- pinch of grass seeds
- pinch of clover seeds
- pond snails
- 2 *Anacharis* strands
- 10 *Daphnia*
- 3 *Fontinallis* strands
- *Chlamydomonas*
- 4 guppies or platys

Background

1. How are living things affected by nonliving things in the environment?
2. Relate the theme of interdependence among organisms to ecosystems.
3. How do different types of organisms interact?

Experiment Setup

1. In this investigation, you will observe organisms in one of three different ecosystems. Look at the organisms listed in the materials list and choose the ecosystem you would like to observe. Which organisms might be the most numerous? Which organisms might decrease in number? Hypothesize how the organisms will interact.
2. Form a group with classmates who have all chosen the same ecosystem. As a group, prepare the environment in a jar with a chosen substrate. Go to Part A, Part B, or Part C for set-up instructions for your ecosystem.
3. Put lids on the containers, and let the ecosystem remain undisturbed in indirect sunlight for a week. Go to Part D after one week.

PART A Setting Up Ecosystem 1

1. Place the soil in the bottom of the jar about 4 or 5 in. deep. Clean soil off the inside of the jar.
2. Place rocks in and on top of the soil in a natural-looking arrangement.
3. Moisten the soil carefully. Do not saturate the soil.
4. Plant the seeds according to the package instructions.
5. Clean up your materials and wash your hands before leaving the lab.

PART B Setting Up Ecosystem 2

6. Place about 2 in. of clean gravel in the bottom of the jar.
7. Gently fill the jar with pond water or dechlorinated tap water until the jar is about three-fourths full.
8. Add the plants and algae to your ecosystem.
9. Clean up your materials and wash your hands before leaving the lab.

PART C Setting Up Ecosystem 3

10. Place a small, clear glass container, such as a mayonnaise jar, inside the larger jar and against one side.
11. Carefully place soil in the larger jar, filling around the smaller jar so that you can see through both jars on one side. Do not place any soil on the side where the two jars touch. Clean any soil from the sides of the jar that may obstruct your view.
12. Place some rocks on the soil, and moisten the soil carefully.
13. Place 1 in. of gravel inside the smaller jar and gently fill with pond water or dechlorinated tap water to the level of the soil.
14. Place the algae and the aquatic plants in the water. Plant the grass seeds and clover seeds in the soil in separate areas of the jar.
15. Clean up your materials and wash your hands before leaving the lab.

PART D Observing Your Ecosystem

16. Place the chosen animals in the jar and loosely replace the lid.
17. Observe the jar for a few minutes daily.
18. Make a chart in your lab report to record the original number of each species in your ecosystem. Record daily any changes you observe.
19. Make a graph for each species in your chart, and plot the number of organisms as a function of time. Place a clear acetate sheet over each graph. Using a pen used for overhead transparencies, trace each graph onto the acetate sheet. Use a different colored pen and a different acetate sheet for each organism.
20. Compare the acetate sheets of two organisms that you hypothesized would interact—a predator and its prey, for example. Hold one sheet on top of the other and analyze both graphs. Record the results in your lab report.
21. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. What happened to the organisms in your ecosystem? How did their population sizes change?
2. What are some possible causes of the change in the populations you observed?
3. Construct a food chain for the ecosystem you observed. Which organisms were producers? Which organisms were consumers?
4. What could you learn if you set up more than one jar in an identical manner?
5. How does your ecosystem resemble a natural ecosystem? How does it differ?
6. How did your observation compare with your hypothesis? If the results differed from what you expected, explain what might have caused the difference.
7. Look at your graphs, and determine what kind of relationship exists between predator and prey populations.
8. How would you modify the ecosystem if you were to repeat this investigation?

Further Inquiry

Develop an experiment to study the effects of certain abiotic factors—including temperature, light, and moisture—on the organisms in the ecosystem you constructed.

CHAPTER 23

Environmental Science

Gorillas are one species whose survival is threatened by the growing human population.

FOCUS CONCEPT: ***Interdependence of Organisms***

As you read, notice how a knowledge of biology helps us understand larger environmental processes.

BIOLOGY INTERACTIVE TUTOR **Unit 7—*Ecosytem Dynamics***
Topics 1–6

HUMANS AND THE ENVIRONMENT

In Chapter 22, you learned how environmental factors influence organisms within particular ecosystems. Large-scale environmental forces also have significant effects on human populations. A new field of study called ***environmental science*** *uses biological principles to look at the relationships between humans and the Earth. Environmental science is becoming increasingly important because humans are rapidly changing the global environment.*

OBJECTIVES

▲ Give an example of how global systems are linked together.

● Identify several effects of El Niño on human populations.

■ Describe two ways that humans have modified the composition of the atmosphere, and identify the possible consequences of these changes.

◆ Explain how future human population growth could affect the environment.

A GLOBAL CONNECTION

You might not guess that wind patterns off the coast of Australia would have anything to do with fish harvests in South America or winter weather in the United States, but they do. What connects these events is a complex interaction between air and water currents that is first set in motion by solar energy. When the sun's rays strike air near the surface of the Earth, the molecules are heated and the air, which becomes less dense, starts to rise. As the air rises, it gets closer to outer space and eventually starts to cool. Cooling air becomes more dense and sinks. We can draw this pattern of rising and falling air using a loop called a **convection** (kuhn-VEK-shuhn) **cell.** Groups of convection cells form the system of global air circulation that helps determine climate, as shown in Figure 23-1.

In the southern Pacific Ocean, the usual pattern of convection cells creates a wind that blows from east to west and pushes warm surface water

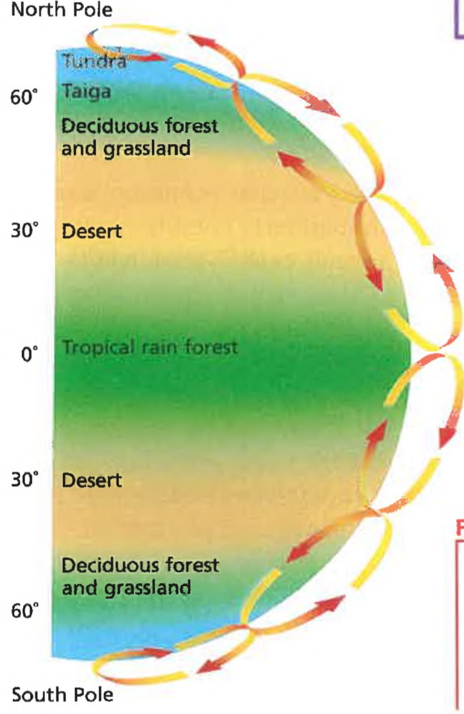


FIGURE 23-1
Warming and cooling air form loops called convection cells in Earth's atmosphere. These air currents influence where different ecosystems are located and also create oceanic circulation patterns.

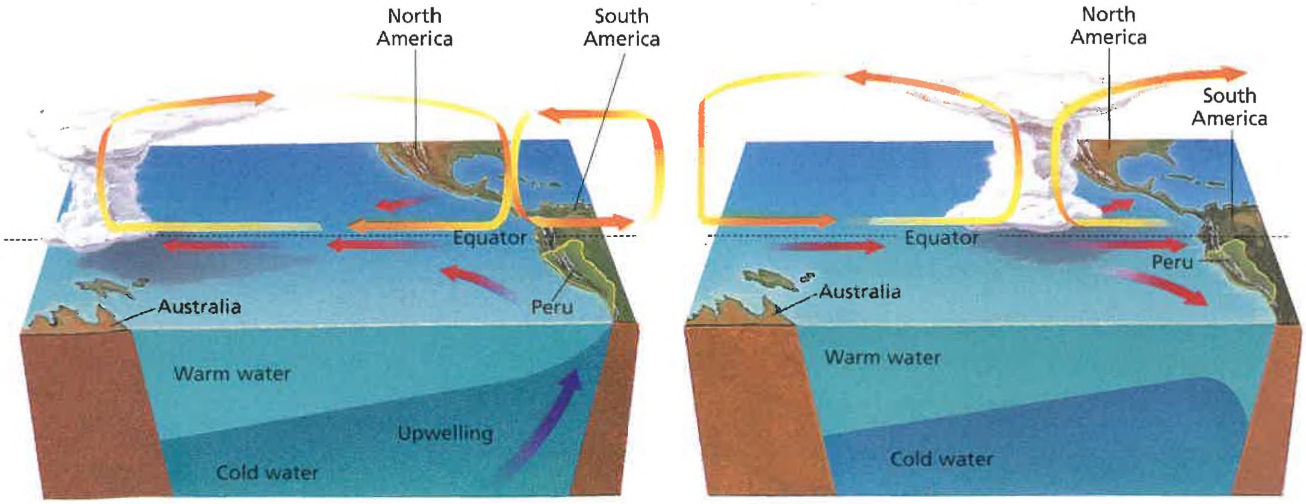


FIGURE 23-2

These two drawings show a comparison of water and atmospheric circulation in normal (left) and El Niño (right) years. The red arrows indicate the movement of warm oceanic currents, and the yellow arrows indicate the movement of air. In an El Niño year, the cold upwelling is blocked by warm water moving toward the coast of Peru.

from South America toward Australia, as shown in Figure 23-2. Along the South American coast, cold water rises from deeper in the ocean and replaces the warm water. This rising current is called an **upwelling,** and it brings with it organic material and nutrients that support an abundance of plankton. The plankton, in turn, support large populations of fish.

One kind of fish that is abundant in these conditions is the anchovy, a main export of the South American country of Peru and a popular pizza topping. Anchovies provide a livelihood not only to fishermen but also to packers, shippers, netmakers, boat builders, and other workers. Diving sea birds eat anchovies too. When these birds come back to shore to roost and digest their food, they excrete a white phosphorus-rich substance called guano. Some guano deposits are dug up and sold as high-quality fertilizer, another major Peruvian export.

El Niño

The Peruvian economy, along with sea birds, depends 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, as illustrated in Figure 23-2. When these conditions occur, the warm surface water cuts off the upwelling of nutrients. This event is called **El Niño** (meaning "the child") because it usually happens near Christmas.

With fewer nutrients, the fish populations decline and Peruvian anchovy exports decrease. Fewer anchovies mean fewer birds and reduced guano production. 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, leading to reduced grain production there. The southeastern United States gets higher rainfall in El Niño years, boosting agriculture while also decreasing forest fires.

internetconnect

SCILINKS NSTA

TOPIC: El Niño
GO TO: www.scilinks.org
KEYWORD: HM442

HUMAN INFLUENCES ON GLOBAL SYSTEMS

Global systems, such as the interconnected system of convection cells, link people and economies from across the world. Examine the following examples of how humans have unintentionally changed the global systems on which we depend.

Declining Ozone

As you learned in Chapter 14, ozone, O_3, is a naturally occurring gas that is vital to life on Earth. Ozone in the upper atmosphere screens out most of the ultraviolet radiation from the sun that causes mutations. Humans, if exposed to ultraviolet radiation, suffer increased rates of skin cancer and cataracts (clouding of the lens of the eye). People are advised to wear sunscreen and sunglasses to protect against the ultraviolet radiation that is not blocked by ozone.

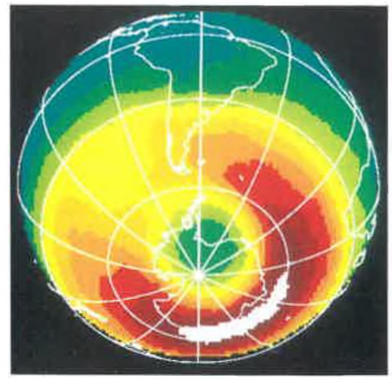
Several kinds of human-made chemicals are diminishing the ozone shield, allowing more ultraviolet radiation to reach the Earth's surface. The most important of these ozone-destroying chemicals are known as **chlorofluorocarbons,** or CFCs. Originally thought to be harmless, CFCs have been used as coolants in refrigerators and air conditioners and as the propellant in aerosol spray cans. They have also been used to make plastic-foam products and to clean electronic equipment. In the upper atmosphere, CFCs act as catalysts that break down ozone much faster than it is formed by natural processes. Scientists have estimated that a single CFC molecule can help destroy up to 100,000 ozone molecules.

Beginning in the 1980s, atmospheric measurements have indicated some alarming declines in ozone levels. Ozone destruction is most severe over the Earth's polar regions, and for a few weeks every year, an ozone "hole," a zone of very low ozone concentration, forms over Antarctica, as shown in Figure 23-3. In 1991 an international study estimated that even a 10 percent worldwide decrease in ozone levels would cause 300,000 new cases of skin cancer in humans. Other organisms, including plants and photosynthetic algae, are also harmed by high levels of ultraviolet radiation, so ozone depletion could modify entire ecosystems over time.

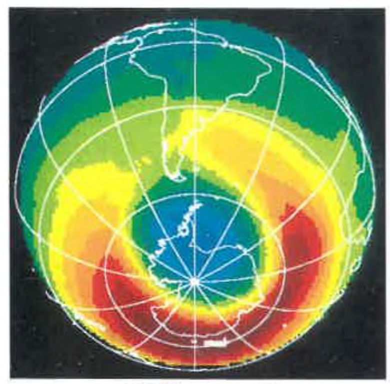
The evidence of widespread and worsening damage to the ozone layer led to international agreements to stop production of CFCs by the end of 1995. Because the substitutes for CFCs are initially more expensive, the developed countries are contributing to a fund to help the developing countries make the changeover. A global environmental success story, these agreements have already cut CFC production by more than 75 percent. Environmental scientists estimate that if the terms of the agreements continue to be followed, the ozone layer will start to build up again, perhaps recovering completely in 50 to 100 years. The effort to protect the ozone layer is a good example of how scientists and policy makers can work together to solve an environmental problem.

FIGURE 23-3

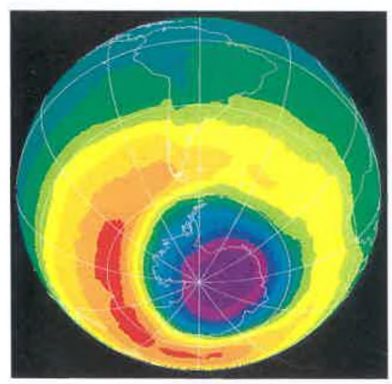
These computer-generated images are based on satellite measurements of ozone levels over Antarctica.



OCTOBER 1979



OCTOBER 1988



OCTOBER 1996

INCREASING OZONE LEVEL →

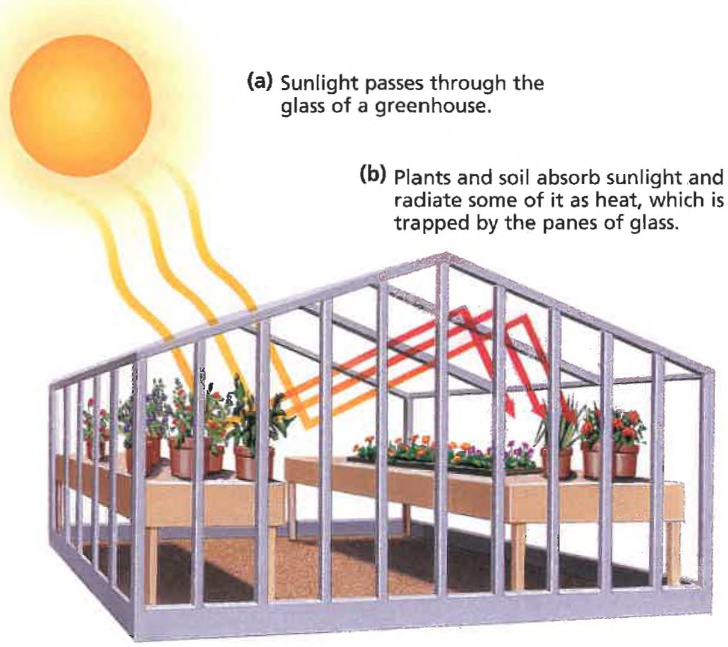


FIGURE 23-4

Solar energy in the form of light penetrates a greenhouse, but the reradiated heat does not immediately escape. In the atmosphere, gases such as carbon dioxide trap heat and warm the surface.

Increasing Carbon Dioxide

Carbon dioxide, CO_2, is a naturally occurring gas that is a raw material of photosynthesis and a byproduct of cellular respiration. It is also released when fossil fuels, such as natural gas, coal, and petroleum, are burned in homes, power plants, and motor vehicles. Around the middle of the nineteenth century, before humans began to substantially increase their use of fossil fuels, carbon dioxide levels in the atmosphere were fairly stable, at about 280 parts per million (ppm). Since 1850, carbon dioxide levels have risen nearly 30 percent, to 360 ppm, and they seem likely to increase as the world's use of fossil fuels grows. According to some projections, by the year 2100 the concentration of CO_2 in the atmosphere might be twice what it was in 1850.

The concentration of carbon dioxide in the atmosphere influences how much heat from the sun is trapped by the atmosphere. The atmosphere's ability to retain heat is called the greenhouse effect. As you can see in Figure 23-4, the glass in a greenhouse allows the sun's rays in but prevents heat from escaping. The same process happens in cars left in the sun with the windows rolled up.

Effects of Rising Carbon Dioxide Levels

If you look at climatic records derived from ice-core samples, shown in Figure 23-5, it is apparent that temperature changes over the last 160,000 years correspond to changes in atmospheric carbon dioxide concentration. Scientists call this type of matching relationship a **correlation.** Because temperature changes correlate with changes in carbon dioxide level, the long-term pattern suggests that a **cause-and-effect relationship** might exist between these two variables. In a cause-and-effect relationship, a change in one variable directly leads to a change in the other variable. Even a strong correlation does not prove the existence of a cause-and-effect relationship, but experiments enable scientists to establish a connection between two variables.

It is not possible to carry out a global experiment that would conclusively demonstrate a cause-and-effect relationship between carbon dioxide levels and rising temperatures. Instead, environmental scientists rely on computer models that simulate the Earth's climate. Because so many factors besides carbon dioxide levels have to be taken into account (wind patterns, ocean temperatures, and effects of ecosystems on CO_2 levels, to name a few), these models are very complicated. It is like predicting the weather hundreds of years in advance.

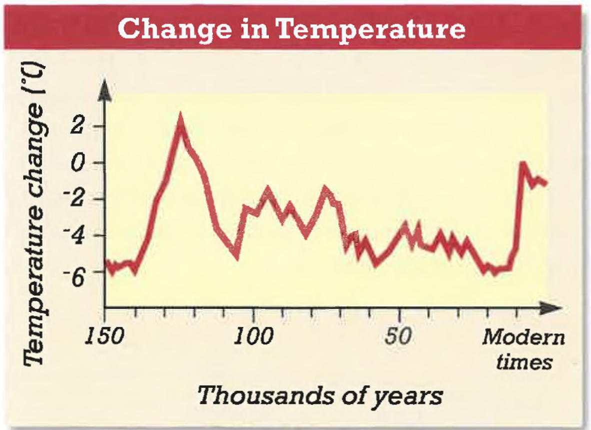
Quick Lab

Calculating CO_2 Production

Materials pencil, paper

Procedure A young tree can remove 11 kg of CO_2 from the atmosphere in a year. Each liter of gasoline burned by a car produces 3 kg of CO_2. Suppose you are taking a trip by car. Your round-trip mileage is 250 km, and you get 13 km/L of gas. Calculate how many young trees are needed in 1 year to remove the CO_2 that was produced from your single trip.

Analysis In 1 year, how many trees are required to remove the CO_2 produced by 100 cars taking the same trip and getting the same number of kilometers per liter? Discuss with your classmates whether your trip was ecologically efficient. What alternative transportation methods might be more ecologically efficient?



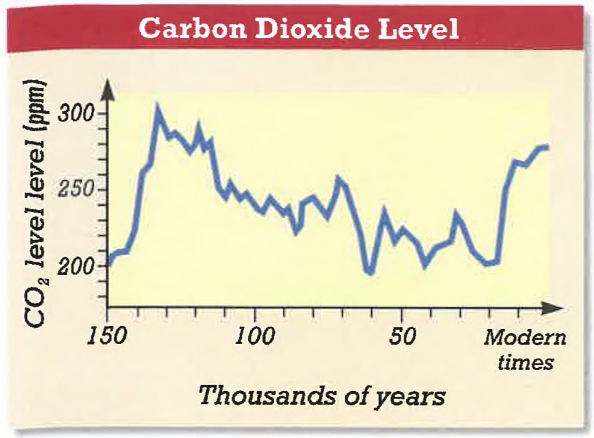


FIGURE 23-5

These graphs show data representing 150,000 years of Earth's climatic history. Although the correlation is not perfect, in general, high levels of carbon dioxide correlate with temperature increases and low levels correlate with temperature decreases. As of 1995, carbon dioxide levels had risen to 360 ppm, higher than any part of this record.

By varying carbon dioxide levels in these climate models, scientists can simulate the possible effects of CO_2 on temperature. The results of these simulations are consistent: doubling carbon dioxide concentration leads to higher average global temperatures—in the range of 1.0°C to 4.5°C (2°F to 8°F). The exact temperature change depends on the particular assumptions built into the model, but nearly all scientists studying this problem have concluded that increased carbon dioxide levels cause temperature increases in the atmosphere.

Measurements of temperatures from around the world support this conclusion. The recent rapid increase in atmospheric carbon dioxide has been accompanied by higher global temperatures, as shown in Figure 23-6. Today the average global temperature is about 0.6°C (1°F) higher than it was in 1860. An international panel of scientists notes that temperatures are expected to rise an additional 2°C (4°F) within the next century. Although this may not seem significant, this increase can have global effects on rainfall patterns, soil moisture, and sea level. These factors might shift agricultural regions of the world and disrupt natural ecosystems. Specific effects on a particular country or state cannot be predicted yet, but most models project that the effects will be felt most strongly in temperate and polar regions.

internet**connect**

SCILINKS. NSTA
TOPIC: Global warming
GO TO: www.scilinks.org
KEYWORD: HM445

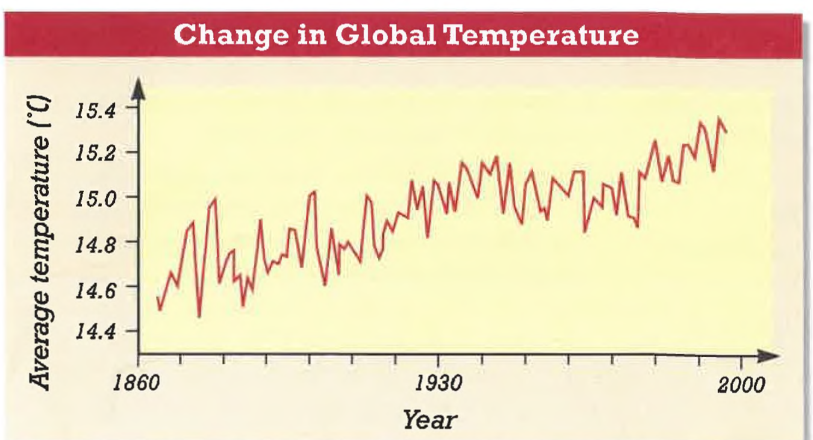


FIGURE 23-6

Although temperatures fluctuate from year to year, a general warming trend is evident over the last 140 years. During this same period, carbon dioxide levels have risen 30 percent, mainly due to the increased use of fossil fuels.

We do not fully understand all aspects of the relationship between carbon dioxide and temperature increases, but most environmental scientists see some potential difficulties for humans and other species if current trends continue. Some scientists have called for international agreements to reduce carbon dioxide emissions. Others think we need to get better information before taking any action, noting some evidence that "excess" carbon dioxide might be absorbed by the oceans and soil.

FUTURE POPULATION GROWTH

You learned in Chapter 20 that the Earth's human population is currently 6 billion and growing at the rate of about 90 million people per year. The United Nations estimates that by the year 2050 the world's population could more than double, to 12.5 billion. How would a doubling of the Earth's population affect ozone levels, carbon dioxide concentrations, and other environmental conditions, such as the availability of clean water, open space, and wildlife habitats?

Although ozone levels may increase and stabilize, doubling the number of people will likely mean more fossil-fuel use and more clearing and burning of forests, which in turn will increase carbon dioxide levels and hasten global warming. Fresh water constitutes less than 3 percent of the water on Earth, and two-thirds of the world's population already lacks a reliable source of drinking water. Doubling the population could also require twice as many homes, schools, hospitals, landfills, and roads, all of which decrease the amount of undeveloped land. Humans already are using 40 percent of the net primary productivity of the Earth; if we double our use, many other organisms will be unable to survive.

SECTION 23-1 REVIEW

1. **What causes the upwelling off the coast of South America? How does this upwelling affect the economy of Peru?**
2. **Describe the consequences of El Niño.**
3. **How have CFCs affected the atmosphere? How might this change affect humans?**
4. **How have scientists used computer models to help understand the effects of rising carbon dioxide levels?**
5. **Describe some possible effects of a continued increase in the human population.**
6. **CRITICAL THINKING Some scientists have argued that rising carbon dioxide levels might lead to increased food production. Explain the logic behind this argument.**

Research Notes

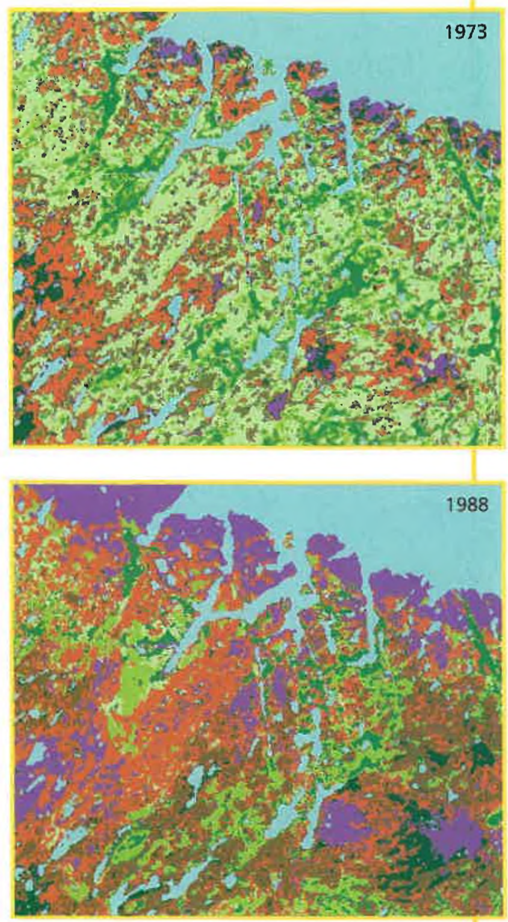
Environmental Eyes in the Skies

Governments, educational institutions, and even private corporations from around the world have sent satellites into orbit to monitor global environmental changes. The satellites use various devices to collect and measure information about Earth's surface and relay it back to Earth, often in "real time." That is, observers on Earth can view the images at the same time the satellite's instruments are observing them.

One system of polar-orbiting satellites, which circle Earth in a north-to-south orbit each day, sends information to the National Oceanic and Atmospheric Administration. These satellites carry equipment that measures clouds, provides temperature and moisture data from Earth's surface through the atmosphere, measures the energy emitted by the sun, and measures radiation striking and leaving the Earth. The satellites also receive emergency signals from people in distress. ARGOS, a French-provided satellite system, collects information from sensors placed in various locations, such as on ships, buoys, weather balloons, and even birds and other animals. The ARGOS satellites provide both short-term information, such as storm warnings, and ongoing information, such as global changes in pollution levels and vegetation cover.

Hans Tømmervik conducts research projects in Tromsø, Norway, a busy seaport located north of the Arctic Circle. Tømmervik's primary concern has been the effect of air pollution on the natural environment of the Norwegian-Russian border area, located hundreds of kilometers east of Tromsø. In one project, Tømmervik and fellow scientists used information from remote-sensing satellites to map changes in the area's vegetation cover from 1973 to 1988. They compared vegetation-cover maps with sulfur dioxide emission levels for the same years. A time sequence of satellite images showed that the area with lichen-dominated vegetation had decreased by 85 percent over 15 years, while desert-like conditions had increased by more than five times. During the same time, emission levels of sulfur dioxide had increased dramatically. The scientists developed a pollution-impact map on the basis of the vegetation maps. The map clearly shows how the impact of pollution varies with distance from the pollution source.

Satellite monitoring of the environment has made large gains since the end of the Cold War between the United States and the former Soviet Union. Satellites that these nations previously used for spying on each other are now being used to monitor environmental conditions. These satellites have much better resolution than satellites currently used for environmental-science information gathering. Some are capable of viewing objects that are less than 15 cm (6 in.) across. The scientific community stands to benefit not only from better equipment but also from international sharing of expertise in designing sensors and interpreting data.



Between 1973 and 1988, a satellite monitored the effects of pollution on a 10,000 km² area along the border between Russia and Norway. One of the main discoveries was that lichen-covered areas (light green on maps) decreased by 85 percent, while there was a fivefold increase in bare, eroded, and damaged areas (violet on maps).

SECTION

23-2

OBJECTIVES

▲ Define *biodiversity,* and explain three ways to measure it.

● Describe global patterns of biodiversity.

■ Identify two strategies for conserving biodiversity in developing countries.

◆ Distinguish between utilitarian and nonutilitarian reasons for conserving biodiversity.

THE BIODIVERSITY CRISIS

Although some extinctions of species are natural events that have been going on since life began, environmental scientists have noted that humans are now causing species to become extinct much faster than in the past. Because extinction is irreversible and stops the evolution of future species, biologists are urgently trying to learn more about how we can conserve species.

BIODIVERSITY

Biodiversity refers to the variety of organisms in a given area. Biodiversity can be measured in several ways. Looking at Figure 23-7, it seems easy to say that Site A has more biodiversity than Site B and less than Sites C and D. Recall from Chapter 21 that the number of species in an area is called species richness. In this example, species richness for Site A is 3, for Site B is 1, for Site C is 4, and for Site D is 4. For quick comparisons between sites, biologists often find that species richness is a very useful estimate of biodiversity.

Now compare Site C with Site D. Each site has four moth species, but the moth communities are not the same. Site C has three individuals of each species of moth, while Site D has one individual of

FIGURE 23-7
This chart shows the number of individuals of four moth species captured at four sites.

each of three species and nine individuals of the fourth species. Even though the species richness (4) and the total number of individuals (12) are the same, biologists would expect these two communities to behave differently. Thus, biologists often determine how many individual organisms belong to each species, a measure called **evenness.** In our example, Site C has greater evenness than Site D. For detailed comparisons between communities, biodiversity is sometimes expressed as a quantity called species diversity (a concept introduced in Chapter 21), which combines species richness and evenness.

Because evolution depends on the presence of genetic variation within a population, as you learned in Chapter 15, some biologists would want to know the genetic makeup of each moth. With this information, biologists can calculate the **genetic diversity,** or amount of genetic variation, for each site. In the long run, genetic diversity might be the most important measure of biodiversity, but it is the one we know the least about.

MEASURING EARTH'S BIODIVERSITY

If we use the species-richness measure of biodiversity, how much biodiversity is there on Earth? Estimates vary, but most biologists are confident that there are at least 10 million species on Earth—and possibly as many as 30 million. These are staggering numbers, especially because, in about 200 years of cataloging, scientists have named and described fewer than 3 million species.

When most people think of nature, they tend to focus on mammals. Humans seem to have a basic attraction to large mammals, especially to those that have big heads, big eyes, and a cuddly appearance like pandas. Yet mammals are a very small fraction of biodiversity. Insects and plants are far more representative of life on Earth, as illustrated in Figure 23-8.

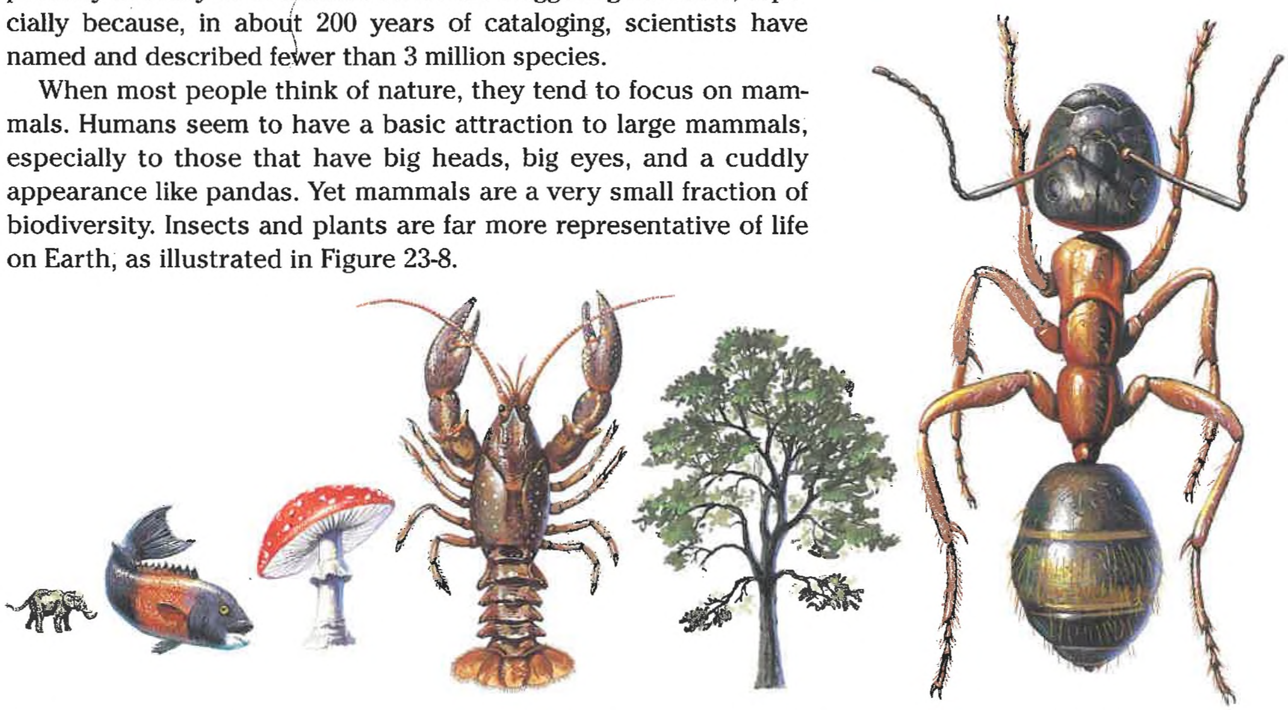
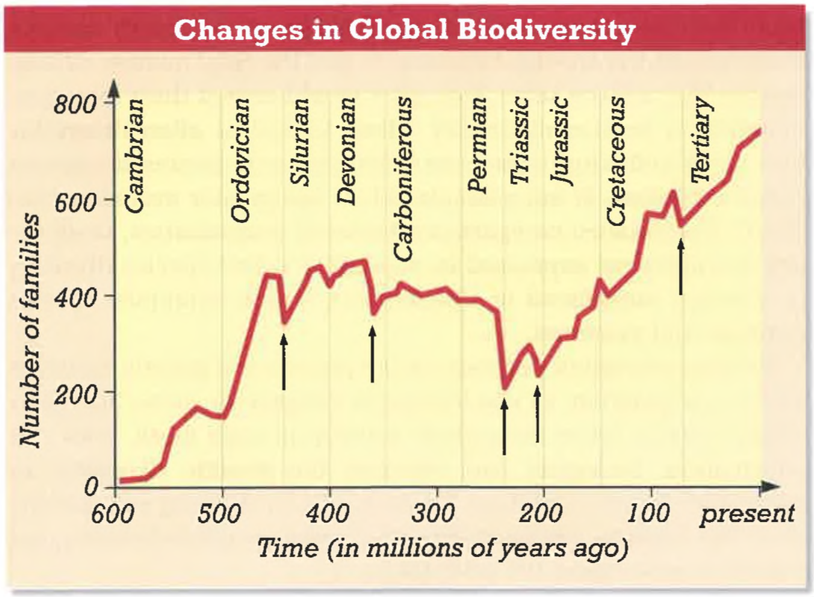


FIGURE 23-8

This diagram shows the known species richness of the Earth, with representatives drawn to a size that is proportional to their abundance. Although people tend to think mainly of mammals, there are many more species of insects and plants. Data from tropical forests, which are still largely unexplored, suggest that insects may represent an even greater fraction of the Earth's biodiversity than is shown here.

FIGURE 23-9

This graph illustrates the changes in biodiversity, measured as the number of families of marine organisms, over time. At present, biodiversity is at an all-time high. Arrows point to the five known mass extinctions. A sixth extinction is under way due to human activities.



Reducing Biodiversity

You can see in Figure 23-9 that we are living in a time of very high biodiversity. But we are also living in a time of very rapid extinction. Biologists estimate that up to 20 percent of existing species may become extinct by the year 2030. As you learned in Chapter 15, five mass extinctions, large and relatively rapid declines in biodiversity, have occurred in the history of life. The mass extinction currently under way is different because humans are the cause. We do not know what the consequences of eliminating millions of species will be.

The greatest threat to biodiversity is the rapid destruction of natural habitats to provide for the needs and wants of the growing human population. In general, humans convert complex, self-sustaining natural ecosystems into simplified systems, such as farmland and urban areas, that cannot sustain as many species. For example, since the discovery of agriculture 10,000 years ago, more than half the world's tropical rain forests have been destroyed, and half of what remains is likely to be gone by the year 2020. Because tropical rain forests have the highest species richness of any biome, containing up to one-fifth of all species on Earth, their destruction is especially damaging to biodiversity.

Ways to Save Biodiversity

The United States became prosperous partly by converting forests and native prairies into farms. The tropics and other regions of high biodiversity often include some of the economically poorest countries on Earth. These countries are trying to use their natural resources to build their economies and raise the standard of living for their citizens, just as the United States did. Several conservation strategies offer ways for developing countries to benefit economically from preserving their biodiversity. For example, in a **debt-for-nature swap,** richer countries or private conservation organizations pay off some of the debts of a developing country. In exchange, the developing country agrees to take steps to protect its biodiversity, such as setting up a preserve or launching an education program for its citizens. Another idea to help local people make money from an intact ecosystem is to set up a national park to attract tourists. People who want to see the ecosystem and its unique organisms will pay money for nature guides, food, and lodging. This idea is called **ecotourism.**

Word Roots and Origins

utilitarian

from the Latin *utilitas,* meaning "useful"

THE IMPORTANCE OF BIODIVERSITY

One way to weigh the importance of biodiversity is called **utilitarian value;** it involves thinking of the economic benefits biodiversity provides to humans. For example, different plants and animals can be harvested for food, and trees can be cut to build homes and provide fuel. Some species are valuable as sources of medicines. Given that most of the world's species have not been named or described, it is reasonable to expect that some undiscovered species will also have medical benefits. Ecosystem functions crucial to our survival, such as the water cycle and nitrogen cycle, depend on living organisms. Harvard University biologist E. O. Wilson summed up the importance of biodiversity when he said, "Biological diversity is the key to the maintenance of the world as we know it."

Another way to weigh the importance of biodiversity is called **nonutilitarian value.** Basically, some people believe that life-forms have value simply because they exist, apart from any human uses of them. Intrinsic value is often associated with moral or religious beliefs that are beyond the scope of biology. Many people attach both utilitarian and nonutilitarian value to biodiversity.

Everyone is familiar with the Declaration of Independence, which led to the separation of the United States from England. Some biologists have called for a "Declaration of Interdependence," an acknowledgment of the connections between organisms, including humans, and their environments. Recognizing interdependence is what environmental science is all about.

SECTION 23-2 REVIEW

1. Explain how species richness and evenness differ.
2. What is genetic diversity?
3. How many species of organisms are there?
4. What is a debt-for-nature swap?
5. List three utilitarian uses of biodiversity.
6. CRITICAL THINKING Explain why the conservation of genetic diversity is necessary for the long-term conservation of biodiversity.

SECTION

23-3

OBJECTIVES

▲ Contrast conservation biology with restoration biology.

● Describe current efforts to conserve migratory birds.

■ Discuss the biological principles and social issues related to wolf reintroduction.

◆ Explain the plan to restore the Everglades.

internetconnect

SCILINKS NSTA
TOPIC: Conservation
GO TO: www.scilinks.org
KEYWORD: HM452

TAKING ACTION

Although biologists have just begun to learn how nature works, they are now being called upon to help conserve threatened wildlife and restore ecosystems. Science, public involvement, and new partnerships have led to several environmental success stories. You too can contribute. Becoming aware of your local environment can link you to community action and global issues.

CONSERVATION AND RESTORATION BIOLOGY

As the human population has increased, the influence of humans on natural ecosystems has also increased. In the United States during the last 200 years, over 99 percent of native prairies have been replaced with farmland or urban development, and most of the old-growth forests have been cut. Loss of so much of these vegetation types has meant losses of biodiversity.

Biologists are being asked to develop plans to protect and manage the remaining areas that still have much of their biodiversity. A new discipline, called **conservation biology,** seeks to identify and maintain natural areas. In areas where human influence is greater—such as agricultural areas, former strip mines, and drained wetlands—biologists may have to reverse major changes and replace missing ecosystem components. For example, returning a strip-mined area to a grassland may involve contouring the land surface, introducing bacteria to the soil, planting grass and shrub seedlings, and even using periodic fires to manage the growth of vegetation. Dealing with a more extreme case like this is called **restoration biology.**

At present, even the best scientific efforts may not be enough to completely restore an area to its original condition. But by using their understanding of ecological principles such as energy flow, species interactions, and biogeochemical cycling, biologists can often make improvements. Let's look at three examples of conservation and restoration biology: the conservation of migratory birds, the reintroduction of the gray wolf to Yellowstone National Park, and new plans to restore the Everglades.

CONSERVING MIGRATORY BIRDS

Imagine weighing as little as 20 g (just a bit more than a floppy disk) and flying nonstop over open ocean for 100 hours before reaching land to rest and feed. This is exactly what blackpoll warblers like the one shown in Figure 23-10 do. The blackpoll warbler is one of the 200 species of **migratory birds** that travel twice each year between North America and Latin America. Migratory birds take advantage of long days and abundant prey in northern tundra and forest ecosystems, where they breed and raise their young. Then, as autumn approaches and the food supply decreases, they fly south to warmer ecosystems that can sustain them during nonbreeding months. Examples of migratory birds you may recognize include the Canada goose, sandhill crane, barn swallow, and scarlet tanager.

Most migratory birds tend to follow generally north-south routes along rivers, mountains, and coastlines. These routes are called **flyways.** Figure 23-11 shows the four major flyways in North America. As many as 5 billion individual birds depend on suitable habitat being available at each end of their migratory journey. Some birds fly along coastlines or over land and make several stopovers for food or rest along the way. If food or habitat is lacking along their way or at their destination, they may not breed and may even die.

FIGURE 23-10

Each fall, blackpoll warblers migrate more than 2,500 km (1,600 mi) over the ocean to reach their wintering grounds in South America.

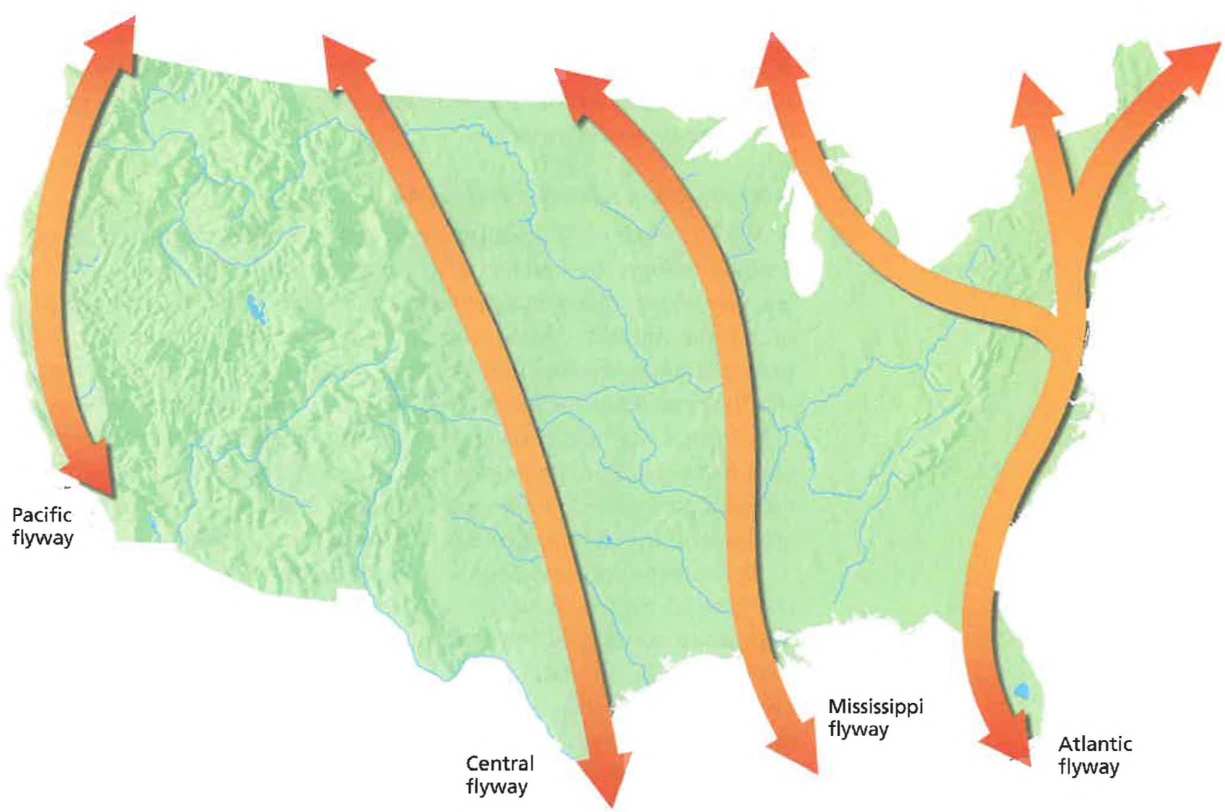
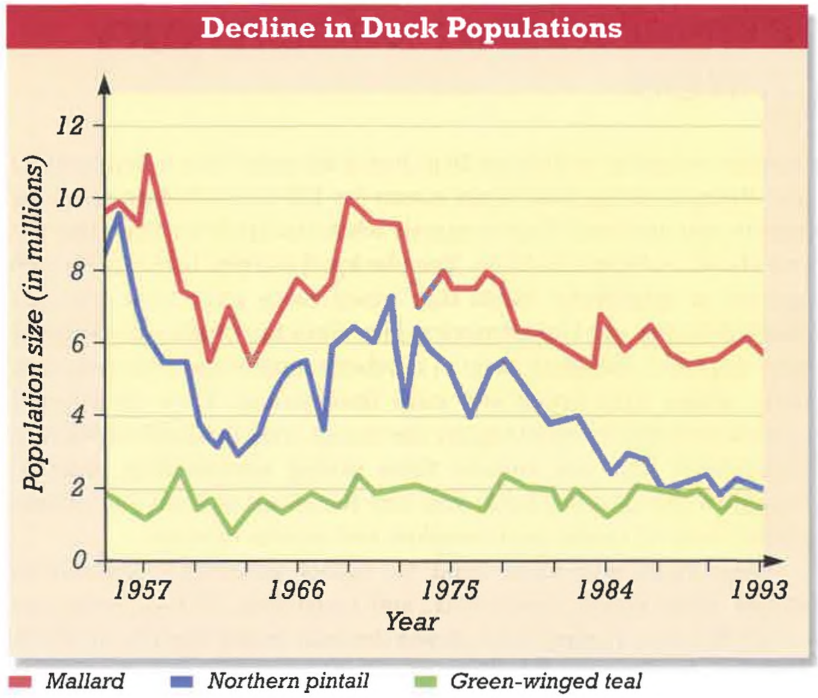


FIGURE 23-11

This map shows the four flyways commonly used by North American migratory birds. Birds tend to follow landscape features such as rivers, mountains, and coastlines.

FIGURE 23-12

Nationwide surveys of breeding populations of ducks indicate long-term declines in some species.



In recent years, scientists, with the help of outdoor recreationists such as hunters and birdwatchers, have documented significant declines in the populations of some migratory birds, including ducks, shorebirds, and songbirds. The number of ducks recorded in the winter of 1993 was the lowest since the surveys began, in 1955, as shown in Figure 23-12. This period was marked by the loss of 60 to 90 percent of prairie wetlands and over 50 percent of all United States wetlands.

Saving Critical Habitat

In 1903, President Theodore Roosevelt established the first national wildlife refuge, to conserve wading birds in Florida. As we have learned more about the preferred travel routes of migratory birds and their habitat and food requirements, biologists have helped propose and develop new wildlife refuges at critical places along the flyways. There are now 500 refuges in the United States, covering about 4 percent of the total area of our country. The refuges are also home to 220 species of mammals, 250 species of reptiles and amphibians, and 200 species of fish, including one-third of all the species on the threatened and endangered species lists.

Because migratory birds also depend on winter habitats outside the United States, conservation efforts have to be international. Migratory songbirds are the focus of a new U.S. Fish and Wildlife Service program, called Partners in Flight–Aves de las Americas, covering the United States and Mexico. The Western Hemisphere Shorebird Reserve Network operates in Central America and South America. Deforestation and coastal development projects remain major threats to migratory birds in these areas.

REINTRODUCTION OF THE WOLF

Gray wolves, shown in Figure 23-13, formerly ranged over most of the United States. For nearly a century, wolves were shot, trapped, and poisoned by people who feared for their own safety or who wanted to protect their livestock. Today the gray wolf is an endangered species, protected by law. In the contiguous 48 states, it is found primarily in Montana and Minnesota. The 1995 total population of wolves in these states was about 2,500 animals. Alaska and Canada have approximately 62,000 wolves.

The current status of wolves in the United States has much to do with human attitudes. Many people fear wolves because of childhood stories. Although sick wolves and wolf-dog hybrids have attacked people, there is no documented case of a healthy wild wolf ever killing a person in North America. Some ranchers regard wolves as threats to their livelihood. As humans have reduced natural-prey populations, some wolves have occasionally attacked livestock to survive. However, only a tiny percentage of livestock in the United States is ever lost to wolf predation. Other people associate positive qualities with wolves. Some view the wolf as a symbol of wilderness, even though wolves are adaptable and do not require wilderness areas to survive.

To a biologist, the wolf is a top carnivore that is dynamically involved with prey species, such as elk and moose. Restoration ecologists became interested in reintroducing wolves to Yellowstone National Park, shown in Figure 23-14, because until about 60 years ago wolves were the top predators of deer, moose, and elk within the park. With the eradication of the wolf—and because no hunting is allowed in national parks—elk populations had grown so large that they may have exceeded the carrying capacity of the park. A proposal was made to reintroduce the wolf to help control elk numbers, to restore a well-known species to the park, and to increase enjoyment of the park for its 3 million annual visitors.

FIGURE 23-13

The gray wolf is an endangered species that is the ancestor of the domestic dog. Adult wolves weigh about 45 kg (100 lb) and are about 2 m (6 ft) long from the nose to the tip of the tail. Wolves are social and commonly form packs with two to eight members.

internet**connect**

SCILINKS NSTA

TOPIC: Wolf
GO TO: www.scilinks.org
KEYWORD: HM455

FIGURE 23-14

Yellowstone National Park is the oldest national park in the United States. Wolves lived there until about 60 years ago, when they were exterminated by hunting.

FIGURE 23-15

Before being released in Yellowstone Park, the wolves were kept in pens for three months to allow them to become accustomed to their new surroundings. This strategy is called soft release.

The Wolf Reintroduction Plan

After many years of public hearings involving people with a wide range of opinions, the National Park Service agreed to reintroduce wolves to Yellowstone. Special precautions were taken to protect the interests of ranchers opposed to the effort. First, ranchers are permitted to kill wolves that are seen attacking their livestock. Second, individual wolves that become a nuisance to humans will be relocated. Third, a private conservation organization, Defenders of Wildlife, set up a $100,000 fund to reimburse ranchers for any economic losses caused by wolves. This group also offers $5,000 to private landowners who agree to let wolves breed on their property. These financial arrangements were key factors in the approval of the reintroduction program.

Before reintroduction, biological information about wolves and Yellowstone was gathered to give the wolves their best chance of survival. In 1995, 14 wolves from Canada were placed in pens at release sites within the park, as shown in Figure 23-15. Fifteen more were released in central Idaho. In 1996, 17 more wolves were released in Yellowstone, and though 11 wolves were killed (some illegally), about 20 pups from both years survived. As of January 1997, the total number of wolves in and around Yellowstone was 40, and their breeding success continues to be monitored.

RESTORING THE EVERGLADES ECOSYSTEM

An enormous amount of biological information must be gathered in order to reintroduce a single species into an ecosystem and monitor it over time. But imagine what is involved in restoring an entire ecosystem that has been severely damaged. A new federal, state, and local partnership has been formed to restore one of the largest and most species-rich national parks in the United States—the Everglades, shown in Figure 23-16.

Early in this century, land developers were attracted to the large beaches and semitropical climates of southern Florida. They found extensive wetlands that were hard to build on and mosquito populations that discouraged new residents. Over time, a series of drainage canals was dug to intercept water moving south from Lake Okeechobee and divert it to the ocean, drying out the land. The non-native melaleuca tree was also planted to take large amounts of water out of the soil.

At that time, few people could foresee the ecological consequences of these actions, but Marjorie Stoneman Douglas did. She helped acquire land to create Everglades National Park and in 1947 wrote a book, *The Everglades: River of Grass,* that explained how the Everglades functioned. It is not stagnant water, but rather a unique, slow-moving river 80 km (50 mi) wide and 15 cm (6 in.) deep. The Everglades is nearly flat and is dominated by saw grass, yet it is home to over 100 species of water birds. Douglas led a lifetime crusade for the Everglades, which in just 50 years experienced a 50 percent reduction in the amount of wetlands, a doubling of salinity in Florida Bay that killed sea grass and shrimp nurseries, and a 90 percent reduction in populations of wading birds. The diversion of water also prevented the ground water from being replenished, creating water shortages for farmers and residents of Miami. Rain washed fertilizers from agricultural fields and polluted the water that did make it to the park. Heavy metals, such as mercury, poisoned park life.

The newly approved 20-year plan for the Everglades ecosystem includes eliminating some of the drainage canals, restoring the Kissimmee River to its original channel, cutting back stands of melaleuca trees, and purchasing more than 40,000 hectares (100,000 acres) for park protection. It is the most ambitious ecosystem-restoration project attempted in the United States.

FIGURE 23-16

Everglades National Park contains only about 20 percent of the Everglades ecosystem. The map below shows some of the key features related to the decline and restoration of Everglades National Park.

GETTING INVOLVED

It is important for individuals to get involved in conservation, and the best place to start is at home. The first step is to learn about your local environment. For example, apply these questions to where you live.

1. *Name five native plants, and determine their seasons. Can they be used for landscaping homes or businesses?*
2. *Name five resident birds and five migratory birds. Are there any special laws that protect them?*
3. *Name two major agricultural crops. How do farmers or ranchers obtain water for crops or livestock?*
4. *Trace the path of water that you use from when it falls as precipitation to when it flows from your faucet. Where does the water go after you have used it, and how is it treated?*
5. *Name three endangered species in your area. If any species have become extinct, what was the cause?*
6. *Trace the path of garbage after it is collected. Does your sanitation department support recycling?*
7. *Describe the primary geological processes that helped form the land where you live. If the land was shaped by water, wind, glaciers, or volcanoes, are any of these still contributing to geologic change?*
8. *Find the names and addresses of two nongovernment conservation associations that are active in your region. Will they allow you to act as a volunteer?*

Exploring these questions may lead you to your own ideas about what you can do to maintain biodiversity or improve the ecological integrity in your area. A new environmental field, called **urban ecology,** involves people who are interested in the challenge of increasing biodiversity in the most heavily developed areas.

SECTION 23-3 REVIEW

1. **How are conservation biology and restoration biology different? How are they similar?**
2. **Why are some populations of migratory birds declining?**
3. **Give three reasons why wolves are being restored to Yellowstone National Park.**
4. **What rules have been made to protect the interests of ranchers concerned about wolves?**
5. **How did the diversion of water from the Everglades lead to environmental problems?**
6. **CRITICAL THINKING What benefits might people living near Yellowstone National Park receive from the reintroduction of wolves?**

CHAPTER 23 REVIEW

SUMMARY/VOCABULARY

23-1

- Currents of air and water are linked into a global system that is responsible for climate.
- El Niño events occur when the normal east-to-west winds across the southern Pacific ocean reverse, causing a variety of effects on organisms worldwide, including humans.
- Over a short time period, humans have affected global systems, including altering the composition of the atmosphere by decreasing ozone levels and increasing carbon dioxide levels.
- Industrial chemicals called CFCs are destroying the ozone layer. A treaty to ban CFC production has been signed.
- From the results of computer models of the atmosphere, a large majority of scientists have concluded that increased carbon dioxide levels have resulted in warmer surface temperatures on the Earth. Scientists expect temperatures to continue to rise as fossil fuel use and carbon dioxide levels increase.

Vocabulary

cause-and-effect relationship (444)
chlorofluorocarbons (443)
convection cell (441)
correlation (444)
El Niño (442)
environmental science (441)
upwelling (442)

23-2

- *Biodiversity* refers to the variety of life found in a given area and can be measured in different ways, including by species richness, evenness, and genetic diversity.
- Scientists estimate that there are at least 10 million species on Earth and may be as many as 30 million. Scientists have described fewer than 3 million species so far.
- Insects and plants make up the majority of species on Earth, especially in tropical rain forests, which are rapidly being destroyed. Two new ideas for conserving tropical biodiversity are debt-for-nature swaps and ecotourism.
- People value biodiversity for utilitarian reasons, which emphasize economic benefits from species. Some of these benefits include medicines, foods, and other useful products, as well as ecosystem services. Nonutilitarian reasons for conserving biodiversity draw on the assertion that living things have intrinsic value. This assertion often derives from moral or religious beliefs.

Vocabulary

biodiversity (448)
debt-for-nature swap (450)
ecotourism (451)
evenness (449)
genetic diversity (449)
nonutilitarian value (451)
utilitarian value (451)

23-3

- Conservation biology and restoration biology are two new disciplines. Conservation biologists are concerned with identifying and maintaining areas that are still relatively undisturbed, whereas restoration biologists are usually involved with repairing badly damaged ecosystems.
- Populations of some migratory birds appear to be in decline due to habitat destruction by humans, but they are being helped by new refuges and international partnerships.
- After a 60-year absence, the gray wolf has been successfully reintroduced in small numbers to Yellowstone National Park to help control elk populations and to increase public enjoyment.
- A new 20-year plan to restore the Everglades ecosystem has recently been approved.

Vocabulary

conservation biology (452)
flyway (453)
migratory bird (453)
restoration biology (452)
urban ecology (458)

REVIEW

Vocabulary

1. Define the term *environmental science.*
2. What are flyways?
3. What chemical elements would you expect to find in chlorofluorocarbons?
4. Describe ecotourism.
5. What is an upwelling, and what connection does it have to El Niño?

Multiple Choice

6. Which of the following is a consequence of El Niño? (a) decreased anchovy production (b) greater number of fires in the southern United States (c) increased guano production (d) ozone depletion
7. Ozone protects organisms from (a) meteor impacts (b) harmful radiation (c) salt depletion (d) cold temperatures.
8. Which of the following is not a use for CFCs? (a) fuel (b) coolant in refrigerators (c) propellant in aerosol cans (d) cleaning electronics.
9. Since 1850, carbon dioxide levels have (a) decreased by 30 percent (b) remained about the same (c) increased by 30 percent (d) not been measured accurately.
10. Which of the following is *not* true of biodiversity?
    (a) It is decreasing.
    (b) It consists mostly of mammals and reptiles.
    (c) It has declined sharply at least five times in the past.
    (d) It is higher in tropical rain forests than in any other biome.
11. Biologists estimate that most species on Earth are (a) insects (b) plants (c) mammals (d) fungi.
12. Benefits from biodiversity include (a) medicines (b) useful products (c) water purification (d) all of the above.
13. Stopovers are used by migratory birds to (a) breed (b) seek new habitat (c) avoid predators (d) feed and rest.
14. Wolves (a) are carnivores (b) need wilderness areas (c) are usually solitary (d) usually attack humans.
15. Which of the following is true about the Everglades ecosystem?
    (a) It is a stagnant swamp.
    (b) It has doubled in size over the last 50 years.
    (c) It supports very few species.
    (d) It has been damaged by pollution.

Short Answer

16. Explain how convection cells are associated with biomes.
17. What happens during El Niño? Describe two ways that El Niño affects the economy of countries other than Peru.
18. What do environmental scientists mean by *interdependence*? Give an example of interdependence from this chapter.
19. Explain the difference between a correlation and a cause-and-effect relationship. How can scientists distinguish between the two?
20. How could future human population growth affect the environment?
21. Describe some of the different attitudes toward wolves. How have these attitudes affected the status of wolves?
22. Which of the communities in the table below has the highest species richness? the greatest evenness? Explain your answers.

Species Richness and Evenness

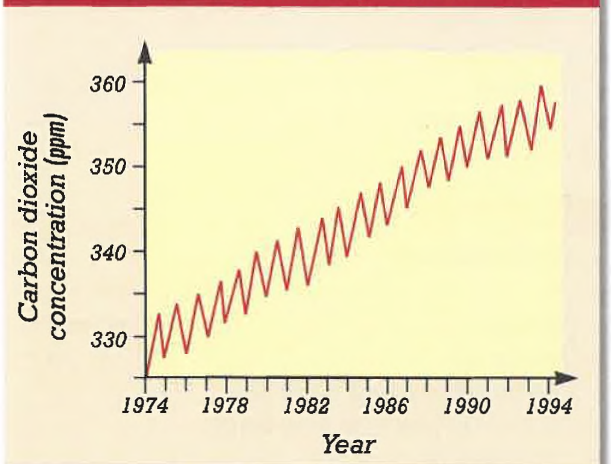
Community	*Number of individuals of each species* 1	2	3	4
A	7	1	1	1
B	3	3	4	0
C	0	9	0	1

23. **Unit 7—*Ecosystem Dynamics***
    Write a report summarizing ways that humans can work to reduce the depletion and pollution of ground water. How would more efficient use of ground water benefit ecosystems?

CRITICAL THINKING

1. You are aware of some of the connections between plankton, anchovies, humans, and birds. Suggest other species interactions that are likely to be influenced by El Niño.
2. The formation of the ozone layer depended on the presence of oxygen in the atmosphere. Drawing on what you have learned about the history of life, explain how organisms affected and were affected by the forming ozone layer.
3. There are no substitutes for clean, fresh water, which is in short supply worldwide. Environmental scientists think fresh water may become a limiting factor on human population growth. Explain how you could estimate Earth's carrying capacity for humans based just on the availability of fresh water. What information do you need in order to make this estimate? How might technological advances change your estimate?
4. What question would you add to the list shown on page 458? Explain your choice. Share your question with your classmates.
5. As part of the global treaty to eliminate CFCs, developed countries are contributing to a fund to help the developing countries buy CFC substitutes. What benefits do the developed countries receive from this investment?
6. It is a widely held belief that the birth rate declines when countries make progress toward industrialization. However, birth rate has declined in Sri Lanka and Costa Rica, countries with minimal industrial development. How might these data be explained?
7. Look at the graph below. Notice that although the long-term trend is toward higher carbon dioxide levels, the carbon dioxide concentration fluctuates during each year, falling in the spring and summer and rising in the fall. What do you think causes this fluctuation?

Increase in CO_2 Levels



EXTENSION

1. In 1995, three scientists—Paul Crutzen, Sherwood Rowland, and Mario Molina—were awarded the Nobel Prize in chemistry for their work on the ozone layer. Use library resources or an on-line database to research each scientist's contribution to our understanding of the ozone layer. Write a short report that summarizes what you have learned.
2. Form a cooperative team with another member of your class. Work with your partner to answer the questions listed on page 458. You may need to consult several sources of information, including the library, an on-line database, local government agencies, and a nearby university, zoo, or botanical garden. When you have answered all of the questions, prepare a poster that displays what you have learned.
3. Read "In the Wake of the Spill" in *National Geographic,* March 1999, on page 96. Describe the ecological disaster that occurred in Alaska's Prince William Sound just after midnight on March 24, 1989. Which was more effective in the recovery of the ecosystem, nature or cleaning crews? Explain. What other unrelated ecological changes are happening in Alaska?

Testing the Effects of Thermal Pollution

OBJECTIVES

- Model the effects of thermal pollution on living organisms.
- Apply the underlying scientific principles to environmental issues.

PROCESS SKILLS

- hypothesizing
- experimenting
- observing
- organizing data
- analyzing data

MATERIALS

- 400 mL beakers, 2
- ice
- hot water
- thermometer
- U-shaped glass tubing, 30 cm long
- 2 corks to fit both ends of the tubing
- 125 mL beaker
- water
- *Paramecium* culture
- hand lens
- stopwatch or clock
- glass-marking pen or wax pencil

Background

1. Some power plants use water from rivers as a coolant. After the water is used, it is much hotter than the water in the river.
2. What is a pollutant?
3. How can heat be considered a pollutant?
4. How can power plants release nonharmful water?

Procedure

1. Discuss the objectives of this investigation with your partners. Develop a hypothesis concerning the effect of temperature on *Paramecium.*
2. Design an experiment using the given materials to test your hypothesis. In your experiment, *Paramecium* will be contained in the U-shaped tube. One large beaker will be filled with ice, and the other large beaker will be filled with hot water. Other materials that you can use in your experiment are listed in your materials list.
3. In designing your experiment, decide which factor will be an independent variable. Plan how you will vary your independent variable. In your lab report, list your independent variable and your method of varying it.
4. Decide which factor will be the dependent variable in your experiment. Plan how you will measure your dependent variable. In your lab report, list your dependent variable and your method of measuring it.
5. In most experiments, a control is necessary. Plan your control, and describe it in your lab report.
6. Discuss your planned experiment with your teacher. Proceed with your experiment only after you have received your teacher's permission to do so.
7. CAUTION **Water hotter than 60°C can scald. Be careful handling hot water, and alert your teacher if you burn yourself.** Fill a 400 mL beaker with ice and water. Make sure that ice remains in the beaker for the entire experiment. Fill another 400 mL beaker with 60°C tap water.
8. In a 125 mL beaker, gently swirl 20 mL of water and 20 mL of *Paramecium* culture. Your teacher will provide aged tap water or spring water for you to use during this step. (Chlorinated water would kill *Paramecium.*)
9. While your partner holds the test tube steady, carefully pour the *Paramecium*-and-water mixture into the U-shaped tube. Fill the tube completely, leaving just enough room for a cork at each end of the tube. Make sure there are no large air bubbles in the tube. Place a cork at each end of the tube.
10. Create a table similar to the one at right to record your data. For example, the table below is designed to

record the number of *Paramecia* in three parts of the U-shaped tube over time. Design your data table to fit your own experiment. Remember to allow plenty of space for recording your data.

11. Proceed with your experiment, using the tube, ice water, hot water, and hand lens to observe any response of *Paramecium* to the environment.
12. As you conduct your experiment, record your results, including the number of *Paramecium* and the time involved, in your data table. Organize your data so that others reading your lab report will be able to understand the results of your experiment.
13.  Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. Did the results of your experiment support your hypothesis? Explain your answer.
2. What effect did heat and cold have on *Paramecium* in your experiment?
3. What evidence do you have that *Paramecium* preferred one temperature range to another?
4. What are some possible sources of error in your experiment?
5. How might a pollutant cause an increase in the number of organisms? Explain.
6. Judging from your experiment, how do you think other organisms might react to a change in water temperature?
7. How could a power plant change the type of organisms that live in the water where it releases its cooling water?

Further Inquiry

Develop a hypothesis about the effects of acid rain on *Paramecium,* and design an experiment to test your hypothesis.

OBSERVATIONS OF *PARAMECIA*

		Number of *Paramecia*		
		Cold end	**Hot end**	**Middle**
	0			
Elapsed	**15**			
time	**30**			
(seconds)	**45**			
	60			
	75			