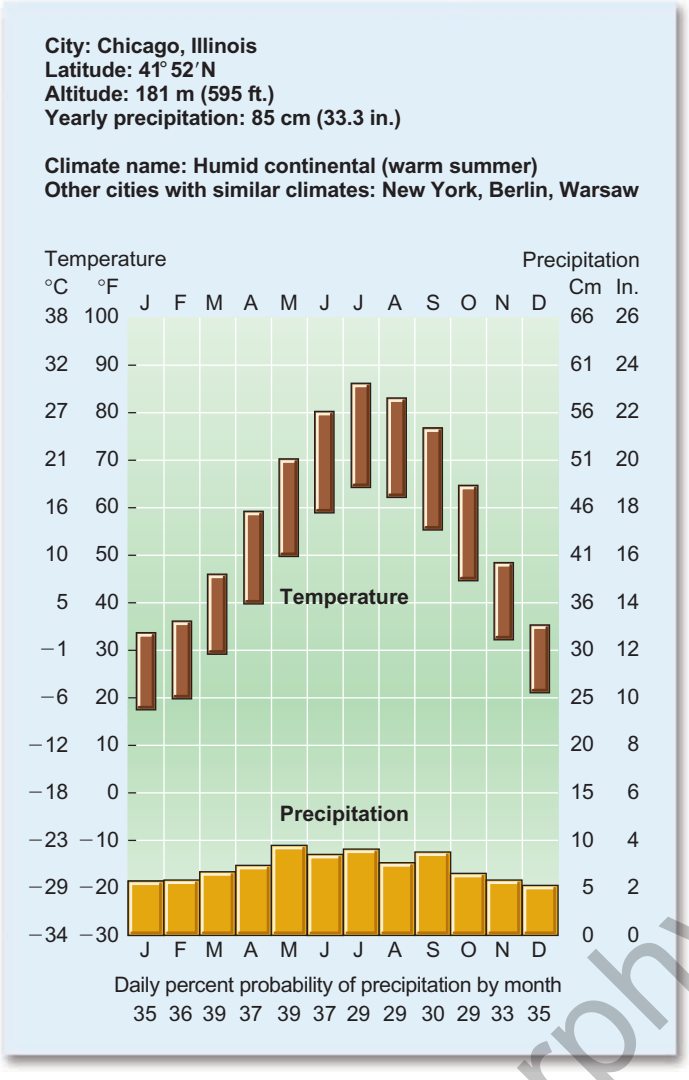


(a)

(b) Temperate deciduous forest in summer

(c) Temperate deciduous forest in fall

(d) Raccoon

FIGURE 16.16 Temperate Deciduous Forest
(a) Climagraph for Chicago, Illinois. *(b & c)* A temperate deciduous forest develops in areas that have significant amounts of moisture throughout the year but where the temperature falls below freezing for parts of the year. During this time, the trees lose their leaves. *(d)* Raccoons are common animals in the temperate deciduous forest of North America. This kind of forest once dominated the eastern half of the United States and southeastern Canada.

in this biome are leaf-eating insects. These insects are food for a variety of birds that raise their young in the forest during the summer and migrate to more moderate climates in the fall. Many other animals, such as squirrels, some birds, and deer, use the trees' fruits for food. Carnivores, such as foxes, hawks, and owls, eat many of the small mammals and birds typical of the region. Another feature of the temperate deciduous forest is an abundance of spring woodland wildflowers, which emerge early in the spring before the trees have leafed out.

The region where temperate deciduous forests exist encompasses a large geographic area with somewhat different climatic conditions in different locations. Therefore, there are differences in the species of trees (and other organisms) usually found in different areas within this biome. For instance, in Maryland the tulip tree is one of the state's common large trees, whereas in Michigan it is so unusual that people plant it in lawns and parks as a decorative tree. Aspen, birch, cottonwood, oak, hickory, beech, and maple are typical trees of the temperate decidous forest. Typical animals of this biome are many kinds of leaf-eating insects, wood-boring beetles, migratory birds, skunks, porcupines, deer, frogs, opossums, owls, and mosquitoes.

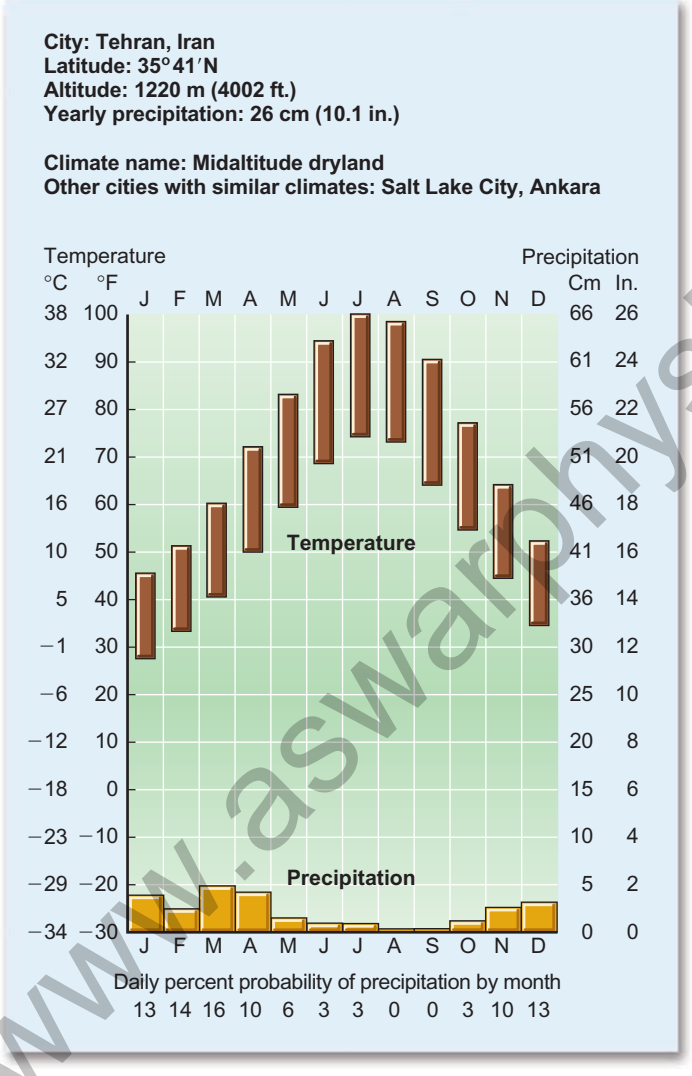
In much of this region, the natural vegetation has been removed to allow for agriculture, so the original character of the biome is gone, except where farming is not practical or the original forest has been preserved or allowed to regenerate.

Temperate Grassland (Prairie)

Temperate grassland, or *prairie,* exists where the rainfall (30 to 85 centimeters per year) is not adequate to support the growth of trees; the dominant vegetation consists of various species of grasses (figure 16.17). Typical are long periods during the year when there is no rainfall. Trees are common in this biome only along streams, where they can obtain sufficient water. Interspersed among the grasses are many kinds of prairie wildflowers. The dominant animals are those that use grasses as food; large, grazing mammals (bison and pronghorn antelope); small insects (e.g., grasshoppers and ants); and rodents (e.g., mice and prairie dogs). A variety of carnivores (e.g., meadowlarks, coyotes, and snakes) feed on the herbivores. Most of the bird species are seasonal visitors to the prairie. At one time, fire was a common feature of the prairie during the dry part of the year.

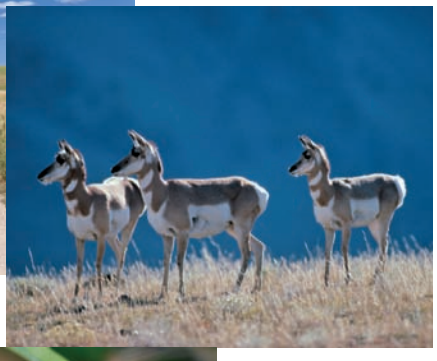
In North America, temperate grasslands are found throughout much of the region between the Mississippi River and the Rocky Mountains. This biome is also common in parts of Eurasia, Africa, Australia, and South America.

Today, most of the original grasslands, like the temperate deciduous forest, have been converted to agricultural uses. Grasslands with adequate rainfall or where irrigation is possible are used to grow crops like corn and wheat. Grasslands that are too dry to allow for farming typically have been used as grazing land for cattle and sheep. The grazing of these domesticated animals has modified the natural vegetation, as has farming in the moister grassland regions.



(a)

(b) Prairie landscape



(c) Pronghorn

(d) Grasshopper

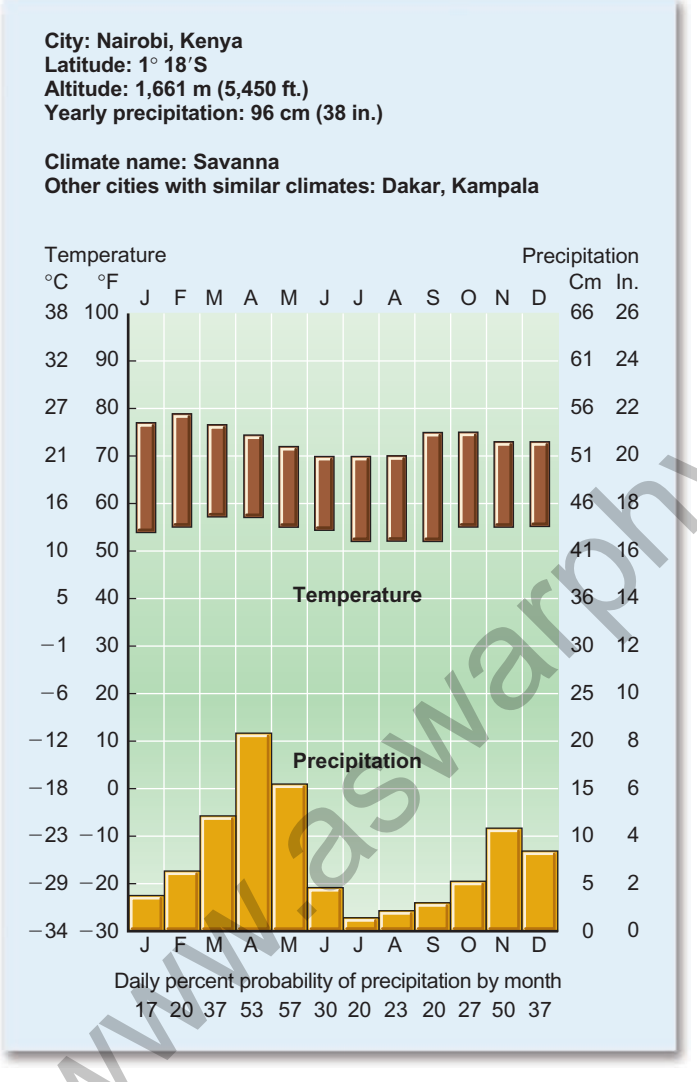
(e) Meadowlark

FIGURE 16.17 Temperate Grassland
(a) Climagraph for Tehran, Iran. *(b)* Grasses are better able to withstand low rainfall than are trees. Therefore, in areas that have moderate rainfall, grasses are the dominant plants. *(c & d)* Pronghorns and grasshoppers are common herbivores and *(e)* meadowlarks are common consumers of insects in North American grasslands.

Savanna

Savannas are tropical biomes of central Africa, northern Australia, and parts of South America; they have distinct wet and dry seasons (figure 16.18). Although these regions may receive 100 centimeters of rainfall per year, there is an extended dry season of 3 months or more. Because of the extended period of dryness, the dominant vegetation consists of grasses. In addition, a few thorny, widely spaced, drought-resistant trees dot the landscape. Many kinds of grazing mammals are found in this biome—various species of antelope, wildebeest, and zebras in Africa; various kinds of kangaroos in Australia; and a large rodent, the capybara, in South America. Another animal common to the savanna is the termite, a colonial insect that typically builds mounds above the ground.

During the wet part of the season, the trees produce leaves, the grass grows rapidly, and most of the animals raise their young. In the African savanna, seasonal migration of the grazing animals is typical. Many of these tropical grasslands have been converted to grazing for cattle and other domesticated animals.

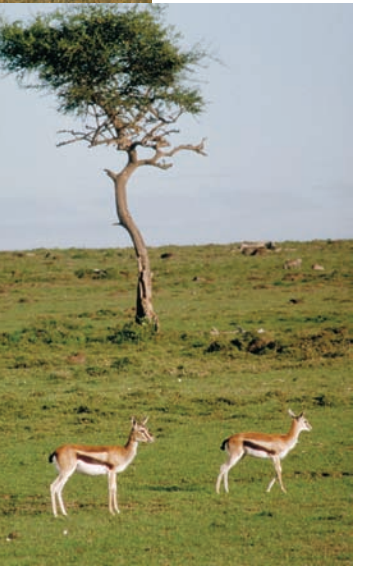


(a)

(b) Savanna landscape

(c) Lion

(e) Secretary birds



(d) Thomson's gazelles

FIGURE 16.18 Savanna
(a) Climagraph for Nairobi, Kenya. *(b)* Savannas develop in tropical areas that have seasonal rainfall. They typically have grasses as the dominant vegetation with drought and fire-resistant trees scattered through the area. Grazing animals such as elephants and gazelles *(b & d)* are common herbivores and lions and secretary birds *(c, e)* are common carnivores in African savannas.

Mediterranean Shrublands (Chaparral)

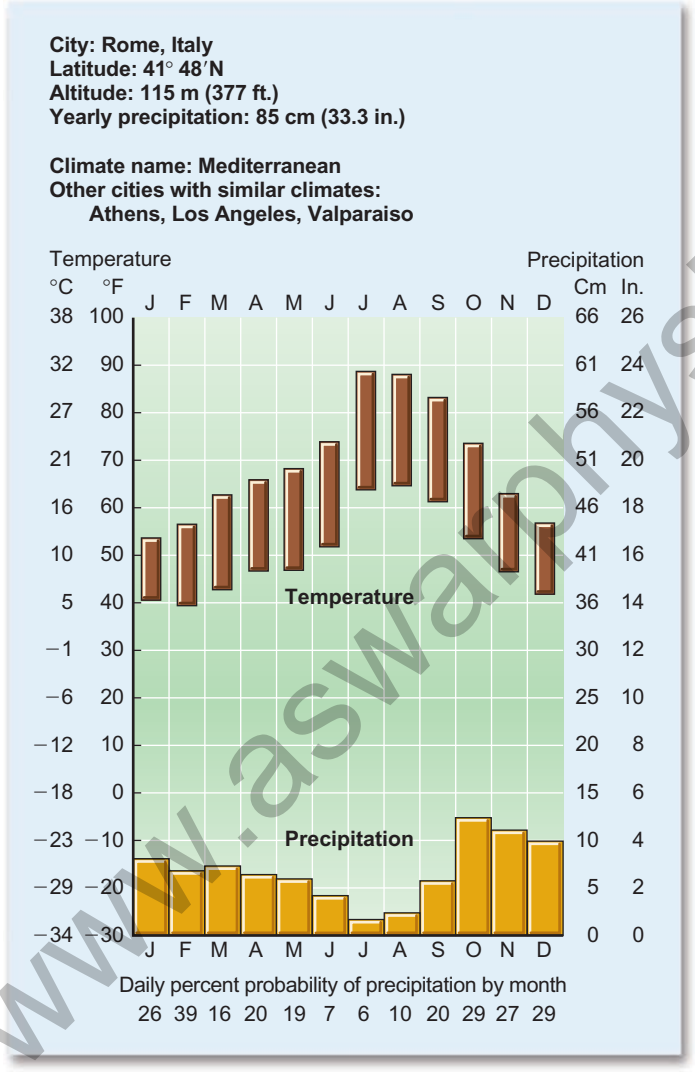
The *Mediterranean shrublands* are located near an ocean and have a climate with wet, cool winters and dry, hot summers. Rainfall is 40 to 100 centimeters per year. As the name implies, this biome is typical of the Mediterranean coast and is also found in coastal southern California, the southern tip of Africa, a portion of the west coast of Chile, and southern Australia.

The vegetation is dominated by woody shrubs that are adapted to withstand the hot, dry summer. Often the plants are dormant during the summer. Fire is a common feature of this biome, and the shrubs are adapted to withstand occasional fires. The kinds of animals vary widely in the different regions of the world with this biome. Many kinds of insects, reptiles, birds, and mammals are found in these areas. In the chaparral of California, rattlesnakes, spiders, coyotes, lizards, and rodents are typical inhabitants (figure 16.19).

Very little undisturbed Mediterranean shrubland still exists. The combination of moderate climate and closeness to the ocean has resulted in all Mediterranean shrublands being heavily altered by human activity. Agriculture is common, often with the aid of irrigation, and many major cities such as Los Angeles and San Diego are located in this biome.

Tropical Dry Forest

The *tropical dry forest* is another biome that is heavily influenced by seasonal rainfall. Tropical dry forests are found in parts of Central and South America, Australia, Africa, and Asia (particularly India and Myanmar). Many of the tropical



(a)

(b) Chaparral landscape

(c) California quail

(d) Black-tailed jack rabbit

FIGURE 16.19 Mediterranean Shrubland (Chaparral)
(a) Climagraph for Rome, Italy. *(b)* Mediterranean shrublands are characterized by a period of winter rains and a dry, hot summer. The dominant plants are drought-resistant, woody shrubs. *(c & d)* Common animals in the Mediterranean shrubland (chaparral) of California are the California quail and black-tailed jack rabbit.

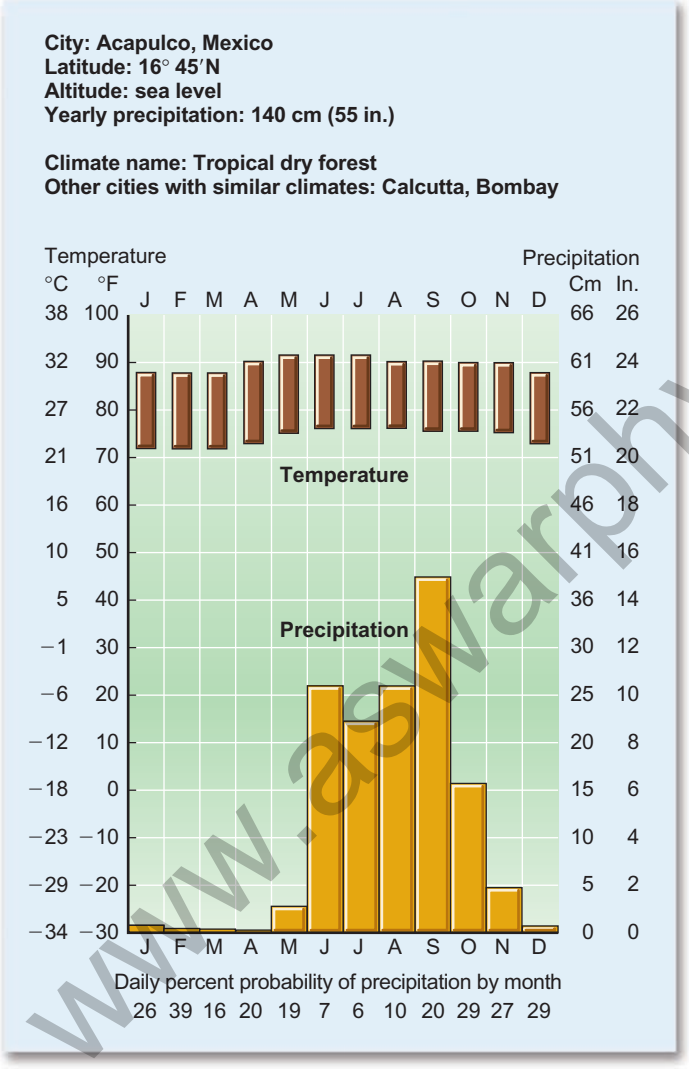
dry forests have a monsoon climate in which several months of heavy rainfall are followed by extensive dry periods ranging from a few to as many as eight months. (See figure 16.20.) The rainfall may be as low as 50 centimeters or as high as 200 centimeters.

Since the rainfall is highly seasonal, many of the plants have special adaptations for enduring drought. In regions that have long dry periods, many of the trees drop their leaves during the dry part of the year. Many of the species of animals found here are also found in more moist tropical forests of the region. However, there are fewer kinds in dry forests than in rainforests.

Many of these forests occur in areas of very high human population. Therefore, harvesting wood for fuel and building materials have heavily impacted these forests. In addition, many of these forests have been converted to farming or the grazing of animals.

Desert

Deserts are very dry areas found throughout the world wherever rainfall is low and irregular. Typically, the rainfall is less than 25 centimeters per year. Some deserts are extremely hot; others can be quite cold during much of the year. The distinguishing characteristic of desert biomes is low rainfall, not high temperature. Furthermore, deserts show large daily fluctuations in air temperature. When the Sun goes down at night, the land cools off very rapidly, because there is no insulating blanket of clouds to keep the heat from radiating into space.



(a)

(b) Tropical dry forest landscape

(c) White-faced coati in Costa Rica

(d) Rhinoceros in Indian tropical dry forest

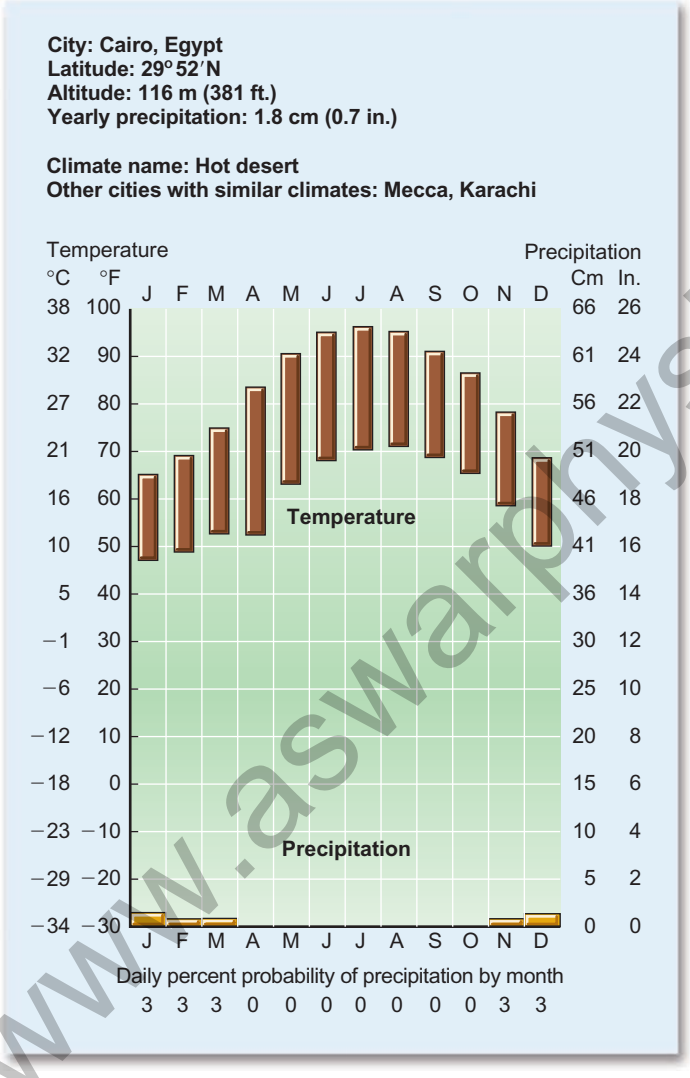
FIGURE 16.20 Tropical Dry Forest
(a) Climagraph for Acapulco, Mexico. *(b)* Tropical dry forests typically have a period of several months with no rain. In places where the drought is long, many of the larger trees lose their leaves. The coati *(c)* is a common animal in the tropical dry forests of the Americas. The endangered one-horned rhinoceros *(d)* is an inhabitant of the tropical dry forest of Asia.

A desert biome is characterized by scattered, thorny plants that have few or no leaves. However, often the stems are green and carry on photosynthesis (figure 16.21). Because leaves tend to lose water rapidly, the lack of leaves is an adaptation to dry conditions. Many of the plants, such as cacti, can store water in their fleshy stems. Others store water in their roots. Although this is a very harsh environment, many kinds of flowering plants, insects, reptiles, and mammals live there. The animals usually avoid the hottest part of the day by staying in burrows or other shaded, cool areas. Staying underground or in the shade also allows animals to conserve water. Many annual plants also live in this biome, but the seeds germinate and grow only after the infrequent rainstorms. When it does rain, the desert blooms.

Boreal Coniferous Forest

Boreal coniferous forest—also known as the *northern coniferous forest* or the *taiga*—is dominated by evergreen trees (conifers) that are especially adapted to withstand long, cold winters with abundant snowfall. This biome is found throughout the world in northern regions, including parts of southern Canada, extending southward along the Appalachian and Rocky Mountains of the United States, much of northern Europe, and Asia.

Typically, the growing season is less than 120 days, and rainfall ranges between 40 and 100 centimeters per year. However, because of the low average temperature, evaporation is low and the climate is humid. Most of the



(a)

(b) Desert landscape

(c) Coyote

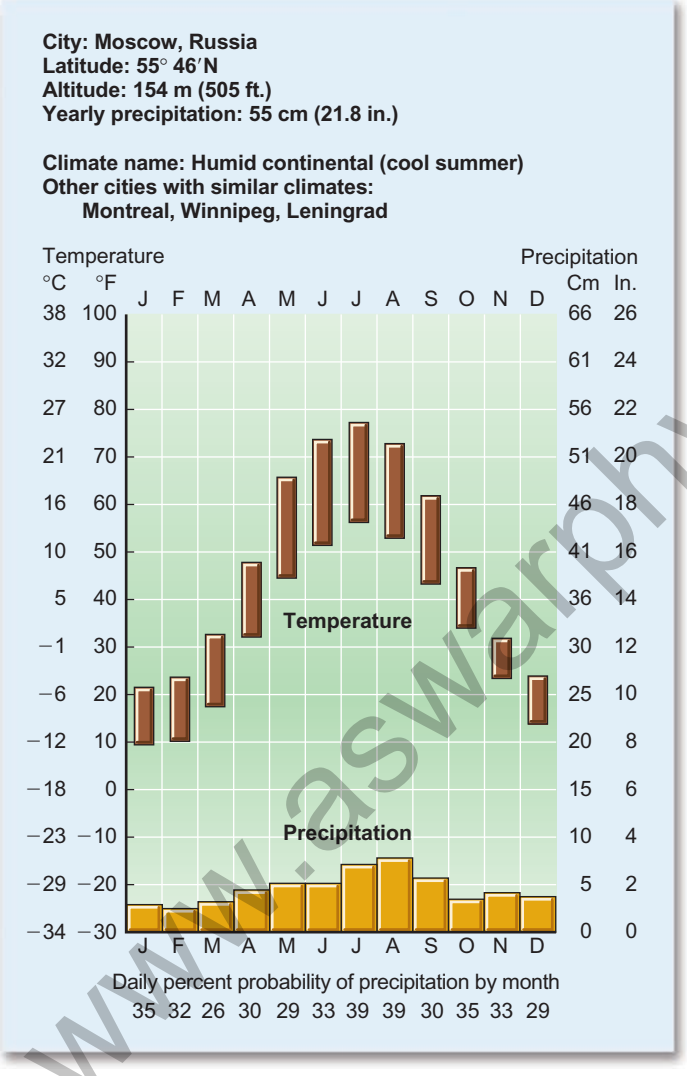
(d) Collared lizard

FIGURE 16.21 Desert
(a) Climagraph for Cairo, Egypt. *(b)* The desert receives less than 25 centimeters of precipitation per year, yet it teems with life. Cacti, sagebrush, lichens, snakes, small mammals, birds, and insects inhabit the desert. *(c)* Coyotes are common in North American deserts. Because daytime temperatures are often high, most animals are active only at night, when the air temperature drops significantly. Cool deserts also exist in many parts of the world, where rainfall is low but temperatures are not high. *(d)* Collared lizards are common reptiles in many deserts of the United States.

trees in the wetter, colder areas are spruces and firs, but some drier, warmer areas have pines. The wetter areas generally have dense stands of small trees intermingled with many other kinds of vegetation and many small lakes and bogs (figure 16.22). The animals characteristic of this biome include mice, snowshoe hare, lynx, bears, wolves, squirrels, moose, midges, and flies. These animals can be divided into four general categories: those that become dormant in winter (e.g., insects and bears); those that are adapted to withstand the severe winters (e.g., snowshoe hare, lynx); those that live in protected areas (e.g., mice under the snow); and those that migrate south in the fall (most birds).

Temperate Rainforest

Temperate rainforest exists in the coastal areas of northern California, Oregon, Washington, British Columbia, and southern Alaska. Temperate rainforest is also found in New Zealand and the southwest coast and tip of South America. In these coastal areas, the prevailing winds from the west blow over the ocean and bring moisture-laden air to the coast. As the air meets the coastal mountains and is forced to rise, it cools and the moisture falls as rain or snow. Most of these areas receive 200 centimeters or more precipitation per year. This abundance of water, along with fertile soil and mild temperatures, results in a lush growth of plants.



(a)

(b) Taiga landscape

(c) Lynx and snowshoe hare

(d) Taiga in winter

FIGURE 16.22 Boreal Coniferous Forest, or Taiga
(a) Climagraph for Moscow, Russia. *(b & d)* The boreal coniferous forest, or taiga occurs in areas with long winters and heavy snowfall. The trees have adapted to these conditions and provide food and shelter for the animals that live there. *(c)* In North America the lynx and snowshoe hare are common animals.

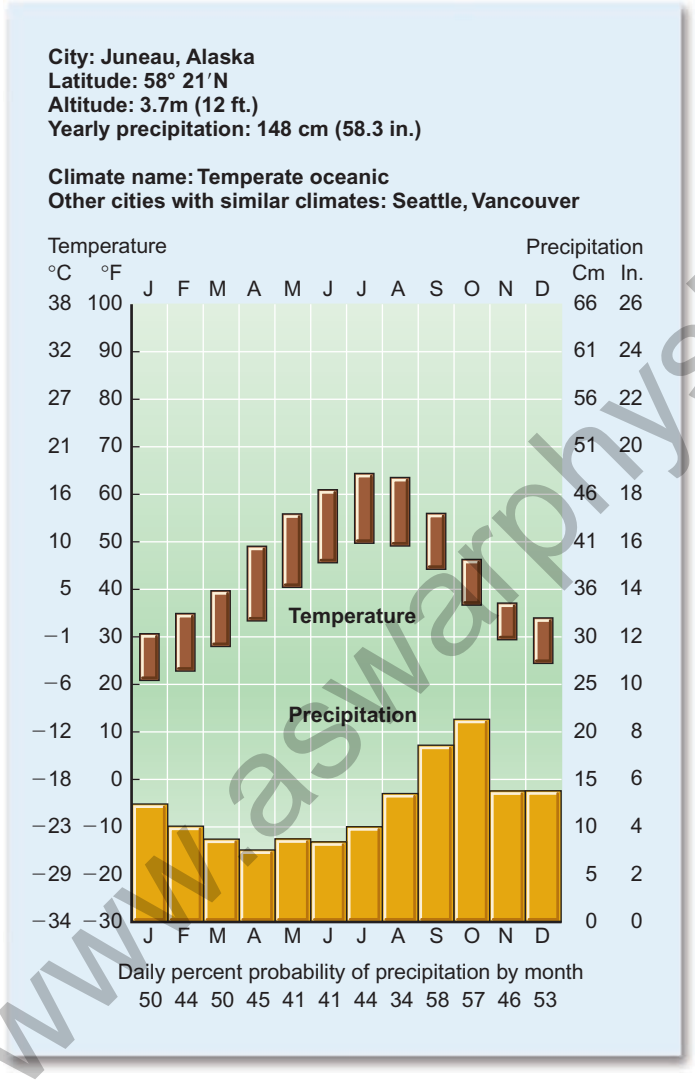
Sitka spruce, Douglas fir, and western hemlock are typical evergreen coniferous trees in the temperate rainforest of North America. Undisturbed (old growth) forests of this region have trees as old as 800 years that are nearly 100 meters tall. Deciduous trees of various kinds (e.g., red alder, big leaf maple, black cottonwood) also exist in open areas where they can get enough light. All the trees are covered with mosses, ferns, and other plants that grow on the surface of the trees. The dominant color is green, because most of the surfaces have a photosynthetic organism growing on them (figure 16.23).

When a tree dies and falls to the ground, it rots in place and serves as a site for the establishment of new trees. This is such a common feature of the forest that the fallen, rotting trees are called nurse trees. Fallen trees also serve as food for a variety of insects, which are food for a variety of larger animals.

Because of the rich resource of trees, 90% of the original temperate rainforest has already been logged. Many of the remaining areas have been protected, because they are home to the endangered northern spotted owl and marbled murrelet (a seabird).

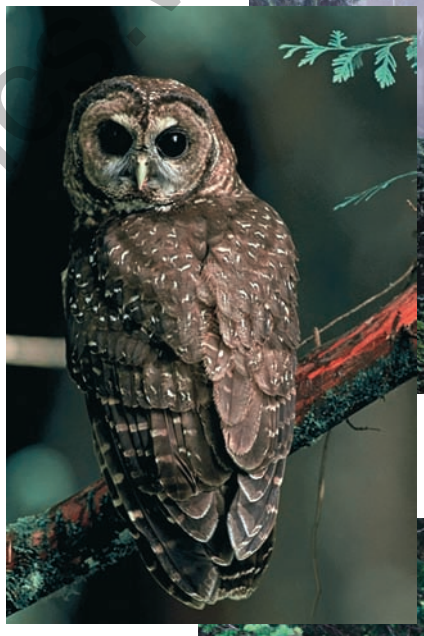
Tundra

Tundra is the most northerly biome (figure 16.24). It is characterized by extremely long, severe winters and short, cool summers. The growing season is less than 100 days and, even during the short summer, the nighttime temperatures approach 0°C. Rainfall is low (10 to 25 centimeters per year). The deeper layers

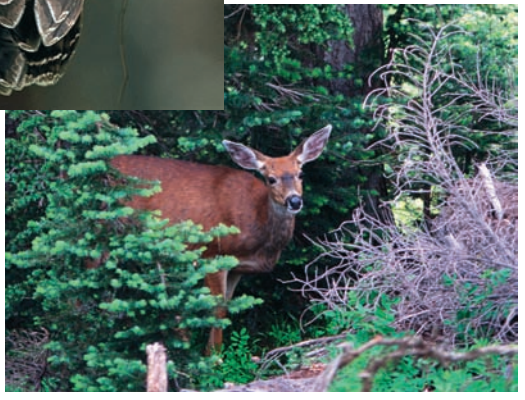


(a)

(b) Temperate rainforest landscape

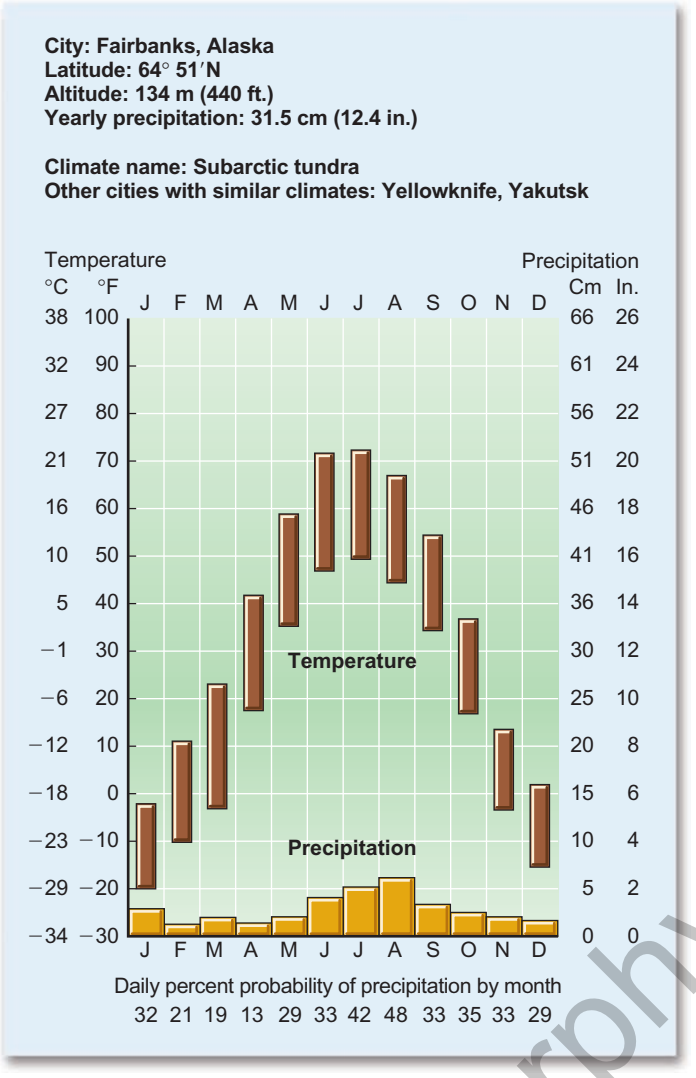


(c) Northern spotted owl



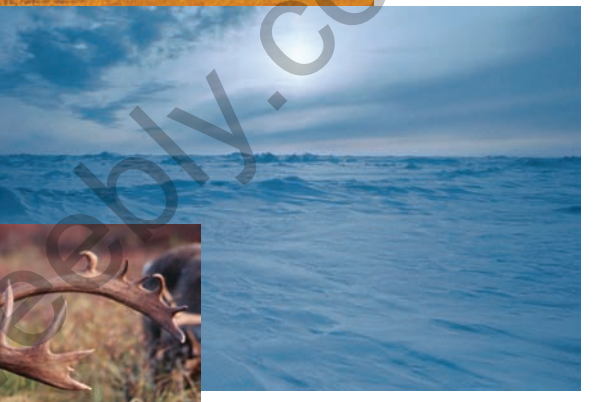
(d) Blacktail deer

FIGURE 16.23 **Temperate Rainforest Biome**
(a) Climograph for Juneau, Alaska. *(b)* The temperate rainforest is characterized by high levels of rainfall that support large evergreen trees and the many mosses and ferns that grow on the surface of the trees. *(c & d)* The blacktail deer is common in this biome, which is also the home of the endangered northern spotted owl.



(a)

(b) Tundra landscape



(c) Frozen tundra

(d) Caribou

(e) Snowy owl

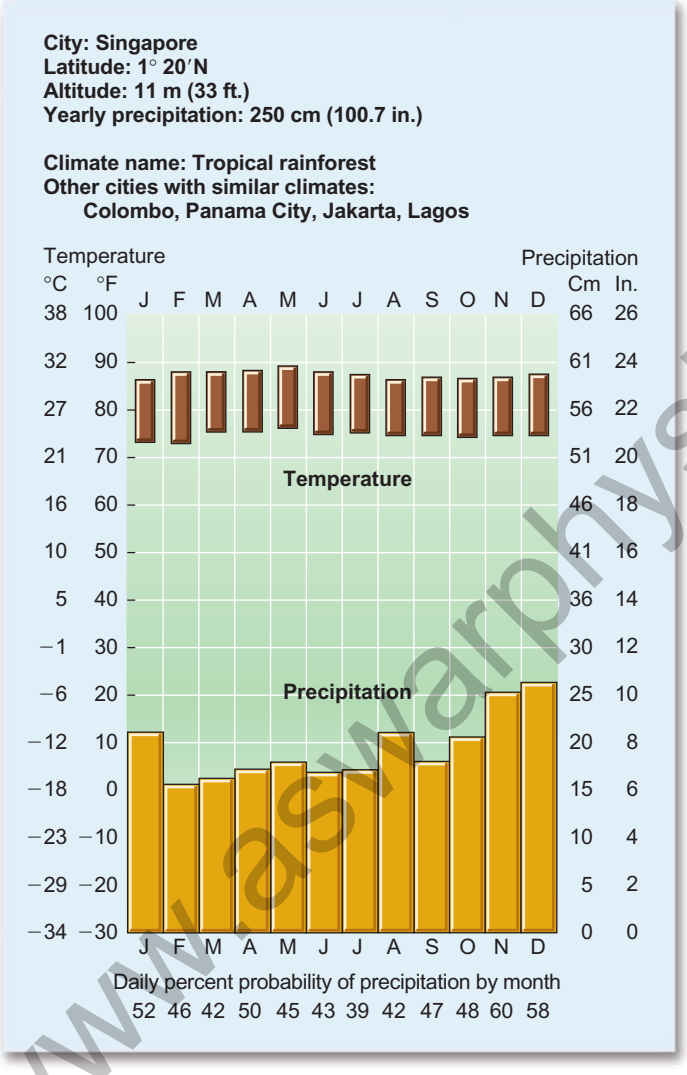
FIGURE 16.24 Tundra
(a) Climagraph for Fairbanks, Alaska. *(b & c)* In the northern latitudes and on the tops of some mountains, the growing season is short and plants grow very slowly. Trees are unable to live in these extremely cold areas, in part because there is a permanently frozen layer of soil beneath the surface, known as the permafrost. Because growth is so slow, damage to the tundra can still be seen generations later. *(d & e)* Caribou and snowy owls are common in the tundra.

of the soil remain permanently frozen, forming a layer called the *permafrost*. Because the deeper layers of the soil are frozen, when the surface thaws the water forms puddles on the surface.

Under these conditions of low temperature and short growing season, very few kinds of animals and plants can survive. No trees can live in this region. The typical plants and animals of the area are grasses, sedges, dwarf willow, some other shrubs, reindeer moss (actually a lichen), caribou, wolves, musk oxen, fox, snowy owls, mice, and many kinds of insects. Many kinds of birds are summer residents only. The tundra community is relatively simple, so any changes have drastic and long-lasting effects. The tundra is easy to injure and slow to heal; therefore, it must be treated gently—the construction of the Alaskan pipeline has left scars that might still be there 100 years from now.

Tropical Rainforest

Tropical rainforest is at the other end of the climate spectrum from the tundra. Tropical rainforests are found primarily near the equator in Central and South America, Africa, parts of southern Asia, and some Pacific islands (figure 16.25). The temperature is high (averaging about 27°C), rain falls nearly every day (typically, 200 to 1,000 centimeters per year), and there are thousands of species of plants in a small area. Balsa (a very light wood), teak (used in furniture), and ferns the size of trees are plants from the tropical rainforest. Every plant has other plants growing on it. Tree trunks are likely to be covered with orchids, many kinds of vines, and mosses. Tree frogs, bats, lizards, birds, monkeys, and an almost infinite variety of insects inhabit the rainforest. These forests are very dense, and little sunlight reaches the forest floor. When the forest is opened up (by a hurricane or the death of a large tree) and sunlight reaches the forest floor, the opened area is rapidly overgrown with vegetation.



(a)

(b) Tropical rainforest landscape

(c) Blue morpho butterfly

(d) Squirrel monkey

FIGURE 16.25 Tropical Rainforest
(a) Climagraph for Singapore. *(b, c, & d)* Tropical rainforests develop in areas with high rainfall and warm temperatures. They have an extremely diverse mixture of plants and animals such as birds, butterflies, and monkeys.

TABLE 16.2 Summary of Kinds of Terrestrial Biomes

Biome	Temperature	Precipitation	Dominant Vegetation
Temperate deciduous forest	Periods of time with temperatures below freezing	Moderate precipitation throughout the year; greater than 75 cm/year	Trees that drop their leaves in the fall
Temperate grassland	Periods of time with temperatures below freezing	Low precipitation; less than 85 cm/year	Grasses and other herbaceous plants; trees uncommon
Savanna	Tropical climate without frost	Abundant rainfall but with extensive dry periods	Grasses and other herbaceous plants; scattered trees
Dry tropical forest	Tropical climate without frost	Abundant rainfall but with extensive dry periods	Trees that drop their leaves during dry periods
Mediterranean shrubland (chaparral)	Moderate temperatures near large oceans	Winter rains and summer drought	Woody shrubs with leathery leaves
Desert	Hot or cold	Very little rainfall; less than 25 cm/year	Woody shrubs with reduced leaves
Boreal coniferous forest	Long periods with temperatures below freezing	Moderate precipitation with much coming as snow in the winter	Coniferous trees
Temperate rainforest	Mild temperatures associated with proximity to ocean	High rainfall; greater than 200 cm/year	Coniferous and deciduous trees
Tundra	Long, cold winters; and short, cool summers; permafrost	Low precipitation; less than 25 cm/year; most comes as snow	No trees; ground-hugging shrubby vegetation
Tropical rainforest	Warm temperatures; no frost	High rainfall throughout the year; greater than 200 cm/year	Tall, broad-leafed trees that do not lose their leaves all at once

Because plants grow so quickly in these forests, people assume the soils are fertile, and many attempts have been made to bring this land under cultivation. In reality, the soils are poor in nutrients. The nutrients are in the organisms; as soon as an organism dies and decomposes, its nutrients are reabsorbed by other organisms. Typical North American agricultural methods, which require the clearing of large areas, cannot be used with the soil and rainfall conditions of the tropical rainforest. The constant rain falling on these fields quickly removes the soil's nutrients, so that heavy applications of fertilizer are required. Often, these soils become hardened when exposed in this way. Although most of these forests are not suitable for agriculture, large expanses of tropical rainforest are being cleared yearly because of the pressure for more farmland in the highly populated tropical countries and the desire for high-quality lumber from many of the forest trees.

Table 16.2 summarizes the distinguishing features of each of the biomes. Outlooks 16.1 describes a special kind of tropical forest that involves periodic flooding.

The Relationship Between Elevation and Climate

The distribution of terrestrial communities is primarily related to temperature and precipitation. Air temperatures are warmest near the equator and become cooler toward the poles. Similarly, air temperature decreases as elevation increases. This means that, even at the equator, cold temperatures are possible on the peaks of tall mountains. Therefore, as one proceeds from sea level to the tops of mountains, it is possible to pass through a series of biomes that are similar to what one would encounter traveling from the equator to the North Pole (figure 16.26).

16.4 CONCEPT REVIEW

9. List a predominant abiotic factor in each of the following biomes: temperate deciduous forest, boreal coniferous forest, temperate grassland, Mediterranean shrubland, tropical dry forest, desert, tundra, temperate rainforest, tropical rainforest, and savanna.
10. List a dominant producer organism typical of each of the following biomes: temperate deciduous forest, boreal coniferous forest, temperate grassland, Mediterranean shrubland, tropical dry forest, desert, tundra, temperate rainforest, and savanna.

OUTLOOKS 16.1

Varzea Forests—Seasonally Flooded Amazon Tropical Forests

The Amazon River and it many tributaries constitute the largest drainage basin (about 40% of South America) and the highest volume of flow of any river system in the world—about 20 percent of worldwide river flow. The water is supplied by abundant rainfall. Many areas receive over 300 cm of rain per year—in the basin and snowmelt from the Andes. Since the snowmelt and, to a certain extent the rainfall, is seasonal, the Amazon and its tributaries are characterized by seasonal flooding. Much of the river basin is flat. The city of Iquitos is about 3,600 kilometers from the ocean but the river at that point is only 100 meters above sea level. Because of the flat terrain, extensive areas along the river are often flooded under several meters of water. The area flooded extends several kilometers from the river. This creates a seasonal wetland forest known as the *varzea*. The land farther from the river that does not flood is known as the *terra firme*.

This seasonally flooded area accounts for about 4% of the total area of the Amazon rainforest. The vegetation of the varzea is different from that of the terra firme because the trees and other vegetation must be able to withstand extensive periods of flooding.

The animals of the river and the varzea are greatly affected by the flooding. Animals of the river move into the forest with the flood and use forest resources as food. Varzea forest areas are critical to the freshwater fisheries of the Amazon Basin. Many fish actually change their diet and become fruit eaters when they are able to enter the flooded forest. In the drier portions of the year when the river recedes, they return to the main river channel and are carnivores. In addition to using the forest for food, the fish also distribute the seeds of fruits in their feces. Other river animals such as the caimans and the giant river otter also move into the forest with the flood.

The terrestrial animals of the forest face a different problem. As the river rises they are forced to retreat to higher ground and often become trapped on islands. This results in intense competition for food. Monkeys and birds are less troubled by the flooding. Many of them rely on fruits of trees, which is available even during the flood, as their primary food source. The monkeys can simply travel from tree to tree and the birds can fly over the water.

The periodic flooding of the area deposits silt, which provides a fertile soil. Therefore, the varzea is affected by human activity as people use the land along the river during the dry season to raise crops. Often the crops are a mixture of normal forest plants along with crops like bananas, rice, and root crops. Because of the flooding, people who live along the river build their houses on high ground and often on stilts. The rivers are also the primary highways of the region and small boats are the most common form of transportation.

The river nearly reaches to the top of this bank during floods that occur every year

Varzea forest

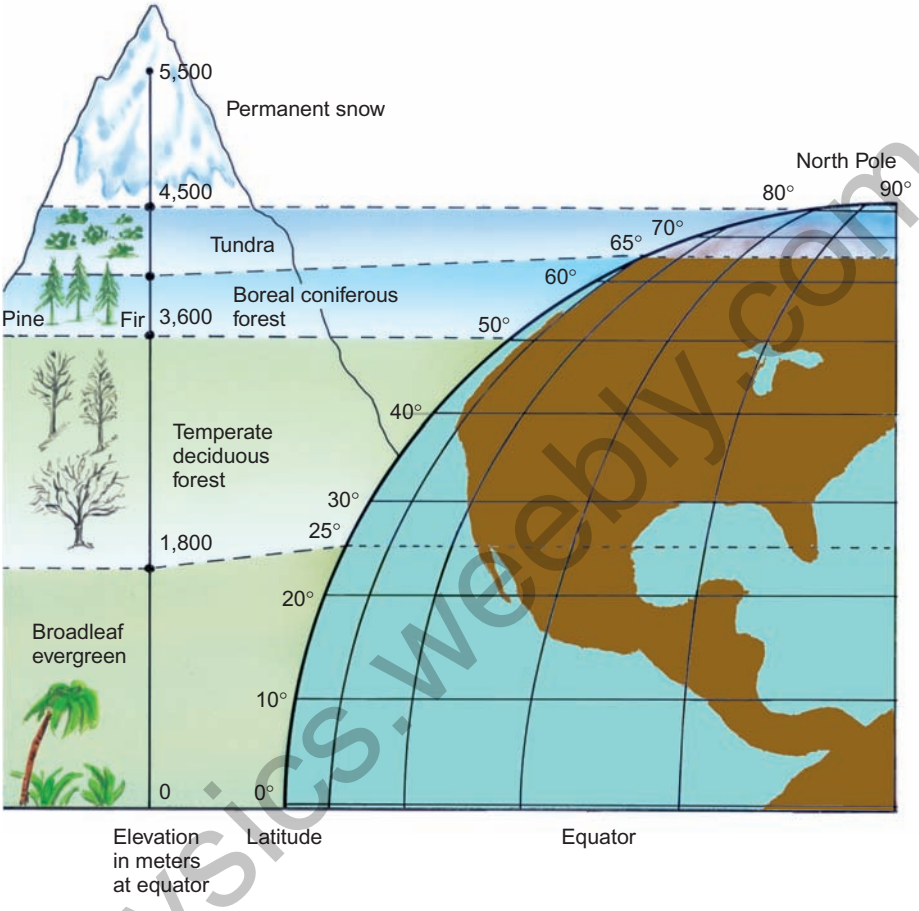


FIGURE 16.26 The Relationship Among Elevation, Latitude, and Vegetation
As one travels up a mountain, one experiences changes in climate. The higher the elevation, the cooler the climate. Even in the tropics, tall mountains can have snow on the top. Thus, it is possible to experience the same change in vegetation by traveling up a mountain as one would experience traveling from the equator to the North Pole.

16.5 Major Aquatic Ecosystems

Terrestrial biomes are determined by the amount and kind of precipitation and by temperatures. Other factors, such as soil type and wind, also play a part. Aquatic ecosystems also are shaped by key environmental factors. Several important factors are: how far the sun's rays penetrate the water, the depth of the water, currents, the nature of the bottom substrate, the water temperature, and the amount of dissolved salts.

An important determiner of the nature of aquatic ecosystems is the amount of salt dissolved in the water. Those that have a high salt content (35 parts per thousand or greater) are called *marine ecosystems,* and those that have little dissolved salt (less than 0.5 parts per thousand) are called *freshwater ecosystems*.

Marine Ecosystems

Just like terrestrial ecosystems, marine ecosystems are quite diverse. Ecologists recognize several categories of marine ecosystems.

Pelagic Marine Ecosystems

In the open ocean, many kinds of organisms float or swim actively. Shrimp, squid, fish, and whales swim actively as they pursue food. Organisms that are not attached to the bottom are called **pelagic** organisms, and the ecosystem they are a part of is called a **pelagic ecosystem.**

The term **plankton** is used to describe aquatic organisms that are so small and weakly swimming that they are simply carried from place to place by currents. As with all ecosystems, organisms that carry on photosynthesis are the base of the energy pyramid. **Phytoplankton** are planktonic organisms that carry on photosynthesis. Most phytoplankton are microscopic, single-celled algae and bacteria. The upper layer of the ocean, where the sun's rays penetrate, is known as the **euphotic zone.** It is in this euphotic zone where phytoplankton are most common. The thickness of the euphotic zone varies with the degree of clarity of the water but in clear water can be up to 150 meters (500 feet) in depth.

Zooplankton are small, weakly swimming animals of many kinds (crustaceans, jellyfish, and juvenile fish), and several kinds of protozoa, that feed on the phytoplankton by filtering the phytoplankton from the water. Zooplankton are often located at a greater depth in the ocean than the phytoplankton but migrate upward at night and feed on the large population of phytoplankton. The zooplankton are in turn eaten by larger animals such as fish and larger shrimp, which are eaten by larger animals such as salmon, tuna, sharks, squid, whales and seals. (See figure 16.27.)

A major factor that influences the nature of a marine community is the kind and amount of material dissolved in the water.

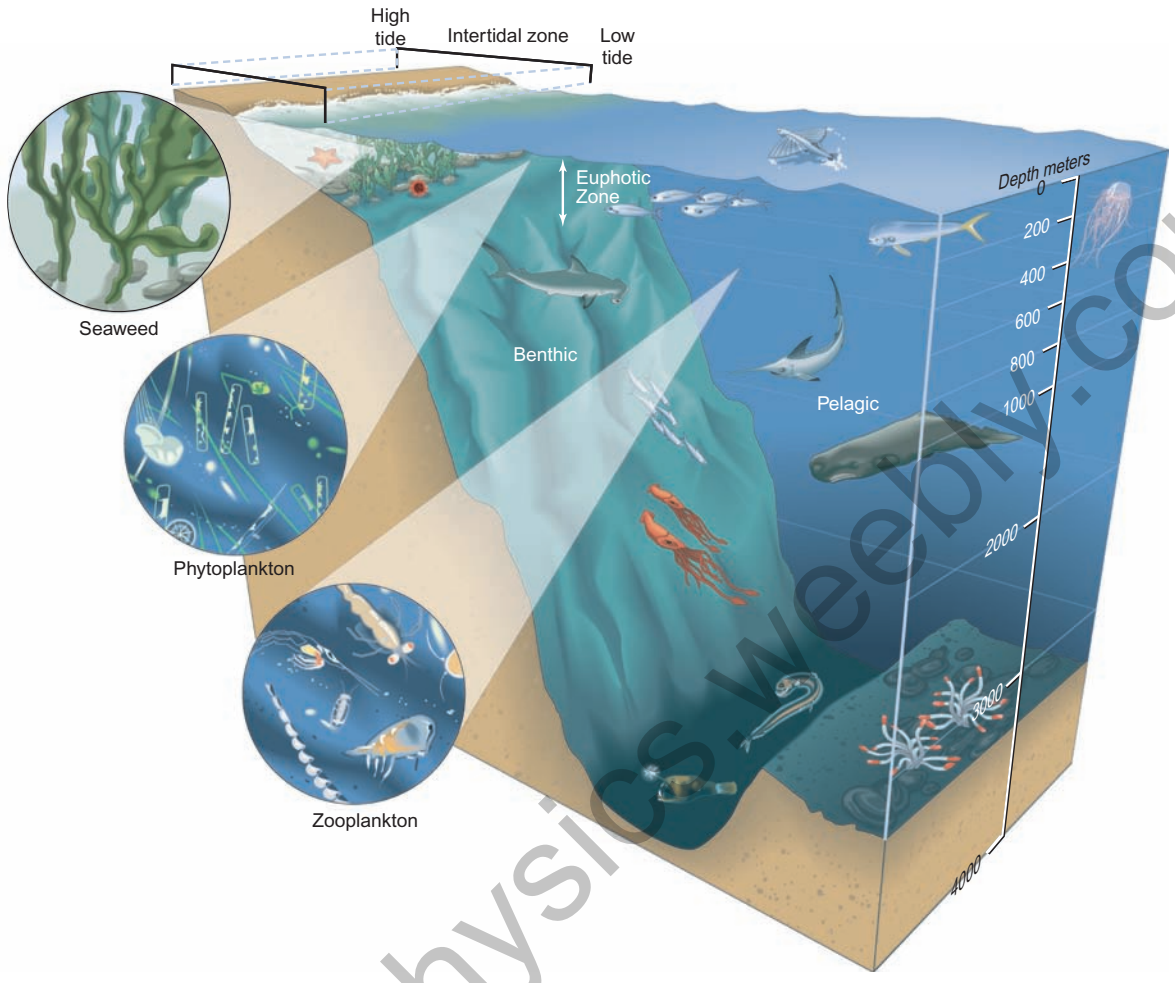


FIGURE 16.27 Marine Ecosystems
All of the photosynthetic activity of the ocean occurs in the shallow water called the euphotic zone, either by attached algae near the shore or by minute phytoplankton in the upper levels of the open ocean. Consumers are either free-swimming pelagic organisms or benthic organisms that live on the bottom. Small animals that feed on phytoplankton are known as zooplankton.

Of particular importance is the amount of dissolved, inorganic nutrients available to the organisms carrying on photosynthesis. Phosphorus, nitrogen, and carbon are all required for the construction of new living material. In water, these are often in short supply. Therefore, the most productive aquatic ecosystems are those in which these essential nutrients are most common. These areas include places in oceans where currents bring up nutrients that have settled to the bottom and places where rivers deposit their load of suspended and dissolved materials.

Benthic Marine Ecosystems

Organisms that live on the ocean bottom, whether attached or not, are known as **benthic** organisms, and the ecosystem of which they are a part is called a **benthic ecosystem.** Some fish, clams, oysters, various crustaceans, sponges, sea anemones, and many other kinds of organisms live on the bottom. In shallow water, sunlight can penetrate to the bottom, and a variety of attached photosynthetic organisms commonly called seaweeds are common. Since they are attached and some, such as kelp, can grow to very large size, many other bottom-dwelling organisms, such as sea urchins, worms, and fish, are associated with them.

The material that makes up the bottom is very important in determining the kind of benthic community that develops. Sand tends to shift and move, making it difficult for large plants or algae to become established, although some clams, burrowing worms, and small crustaceans find sand to be a suitable habitat. Clams filter water and obtain plankton and detritus or burrow through the sand, feeding on other inhabitants. Mud may provide suitable habitats for some kinds of rooted plants, such as mangrove trees or sea grasses. Although mud usually contains little oxygen, it still may be inhabited by a variety of burrowing organisms that feed by filtering the water above them or that feed on other animals in the mud. Rocky surfaces in the ocean provide a good substrate for many kinds of large algae. Associated with this profuse growth of algae is a large variety of animals.

Temperature also has an impact on the kind of benthic community established. Some communities, such as coral reefs or mangrove swamps, are found only in areas where the water is warm.

Coral reef ecosystems are produced by coral animals that build cup-shaped external skeletons around themselves. Corals protrude from their skeletons to capture food and expose themselves to the sun. Exposure to sunlight is important because corals contain single-celled algae within their bodies. These algae carry on photosynthesis and provide both themselves and the coral animals with the nutrients necessary for growth. This mutualistic relationship between algae and coral is the basis for a very productive community of organisms.

The skeletons of the corals provide a surface upon which many other kinds of animals live. Some of these animals feed on corals directly, while others feed on small plankton and bits of algae that establish themselves among the coral organisms. Many kinds of fish, crustaceans, sponges, clams, and snails are members of coral reef ecosystems. Because they require warm water, coral ecosystems are found only near the equator. Coral ecosystems also require shallow, clear water since the algae must have ample sunlight to carry on photosynthesis. Coral reefs are considered one of the most productive ecosystems on Earth (see figure 16.28).

An **abyssal ecosystem** is a benthic ecosystem that occurs at great depths in the ocean. In such deep regions of the ocean there is no light to support photosynthesis. Therefore, the animals must rely on a continuous rain of organic matter from the euphotic zone above them. Essentially, all of the organisms in this environment are scavengers that feed on whatever drifts their way. Many of the animals are small and generate light that they use for finding or attracting food.

Estuaries

An **estuary** is a special category of aquatic ecosystem that consists of shallow, partially enclosed areas where freshwater enters the ocean. The saltiness (0.5–30 parts per thousand) of the water in the estuary changes with tides and the flow of water from rivers. The organisms that live here are specially adapted to this set of physical conditions, and the number of species is less than in the ocean or in freshwater.

Estuaries are particularly productive ecosystems because of the large amounts of nutrients introduced into the basin from the rivers that run into them. This is further enhanced by the fact that the shallow water allows light to penetrate to most of the water in the basin. Phytoplankton and attached algae and plants are able to use the sunlight and the nutrients for rapid growth. This photosynthetic activity supports many kinds of organisms in the estuary.

Estuaries are especially important as nursery sites for fish and crustaceans such as flounder and shrimp. The adults enter these productive, sheltered areas to reproduce and then return to the ocean. The young spend their early life in the estuary and eventually leave as they get larger and are more able to survive in the ocean. Estuaries also trap sediment. This activity tends to prevent many kinds of pollutants from

Coral reef organisms

The Great Barrier Reef–Australia

FIGURE 16.28 Coral Reef

Corals are small sea animals that secrete external skeletons. They have a mutualistic relationship with certain algae, which allows both kinds of organisms to be very successful. The skeletal material serves as a substrate upon which many other kinds of organisms live.

reaching the ocean and also results in the gradual filling in of the estuary, which may eventually become a salt marsh and then part of a terrestrial ecosystem.

Human Impact on Marine Ecosystems

Since the oceans cover about 70% of the Earth's surface, it is hard to imagine that humans can have a major impact on them. However, we use the oceans in a wide variety of ways. The oceans provide a major source of protein in the form of fish, shrimp, and other animals. However, overfishing has destroyed many of the traditional fishing industries of the world such as cod fishing off the east coast of North America. Fish farming in the ocean involves the use of pens to enclose fish. The dense populations in the pens result in pollution of the ocean from the food that is provided to the fish and the waste products the fish produce. These captive populations have also caused diseases to spread from farmed species to wild fish. Estuaries are important fishing areas but are impacted by the flow of fertilizer, animal waste, and pesticides down the rivers that drain farmland and enter estuaries. The use of the oceans as transportation results in oil pollution, and trash regularly floats onto the shore. Coral reefs are altered by fishing and siltation from rivers. Mangrove swamps are destroyed as they are converted to areas for the raising of fish. It is clear that humans have a great impact on marine ecosystems.

Freshwater Ecosystems

Freshwater ecosystems differ from marine ecosystems in several ways. The amount of salt present is much less, the temperature of the water can change greatly, the water is in the process of moving to the ocean, oxygen can often be in short supply, and the organisms that inhabit freshwater systems are different.

Freshwater ecosystems can be divided into two categories: those in which the water is relatively stationary, such as lakes, ponds, and reservoirs, and those in which the water is running downhill, such as streams and rivers.

Lakes and Ponds

Large lakes have many of the same characteristics as the ocean. If the lake is deep, there is a euphotic zone at the top, with many kinds of phytoplankton, and zooplankton that feed on the phytoplankton. Small fish feed on the zooplankton and are in turn eaten by larger fish. The species of organisms found in freshwater lakes are different from those found in the ocean, but the roles played are similar, so the same terminology is used.

Along the shore and in the shallower parts of lakes, many kinds of flowering plants are rooted in the bottom. Some have leaves that float on the surface or protrude above the water and are called *emergent plants*. Cattails, bulrushes, arrowhead plants, and water lilies are examples. Rooted plants that stay submerged below the surface of the water are called *submerged plants*. *Elodea* and *Chara* are examples. This region, with rooted vegetation, is known as the **littoral zone,** and the portion of the lake that does not have rooted vegetation is called the **limnetic zone.** (See figure 16.29.)

Many kinds of freshwater algae also grow in the shallow water, where they may appear as mats on the bottom or attached to vegetation and other objects. Associated with the plants and algae are a large number of different kinds of animals. Adult and larval insects are particularly common in freshwater ecosystems along with fish, crayfish, clams, and many birds and mammals.

Although the water molecule (H_2O) has oxygen as part of its structure, this oxygen is not available to organisms. The oxygen that they need is dissolved molecular oxygen (O_2), which enters water from the air or when it is released as a result of photosynthesis by aquatic plants and other photosynthetic organisms. When water tumbles over rocks in a stream or crashes on the shore as a result of wave action, air and water mix, which allows more oxygen to dissolve in the water. The amount of dissolved oxygen affects the kind of organisms that live in the water.

Streams and Rivers

Streams and rivers are a second category of freshwater ecosystem. Since the water is moving, planktonic organisms are less important than are attached organisms because plankton are swept downstream. Most algae grow attached to rocks and other objects on the bottom. Since the water is shallow, light can penetrate easily to the bottom (except for large or extremely muddy rivers). Even so, it is difficult for photosynthetic organisms to accumulate the nutrients necessary for growth, and most streams are not very productive. As a matter of fact, the major input of nutrients is from organic matter that falls into the stream from terrestrial sources. These are primarily the leaves from trees and other vegetation, as well as the bodies of living and dead insects. Within streams there is a community of organisms that is specifically adapted to use the debris from terrestrial sources as a source of food. Bacteria and fungi colonize the organic matter, and many kinds of insects shred and eat this organic matter along with the fungi and bacteria living on it. The feces (intestinal wastes) of these insects and the tiny particles produced during the eating process become food for other insects that build nets to capture the tiny bits of organic matter that drift their way. These insects are in turn eaten by carnivorous insects and fish.

Organisms in larger rivers and muddy streams, which have less light penetration, rely in large part on the food that drifts their way from the many streams that empty into the river. These larger rivers tend to be warmer and to have slower moving water. Consequently, the amount of oxygen is usually less, and the species of plants and animals change. Any organic matter added to the river system reduces the oxygen in the water as it decays. Plants may becomes established along the river bank and contribute to the ecosystem by carrying on photosynthesis and providing hiding places for animals.

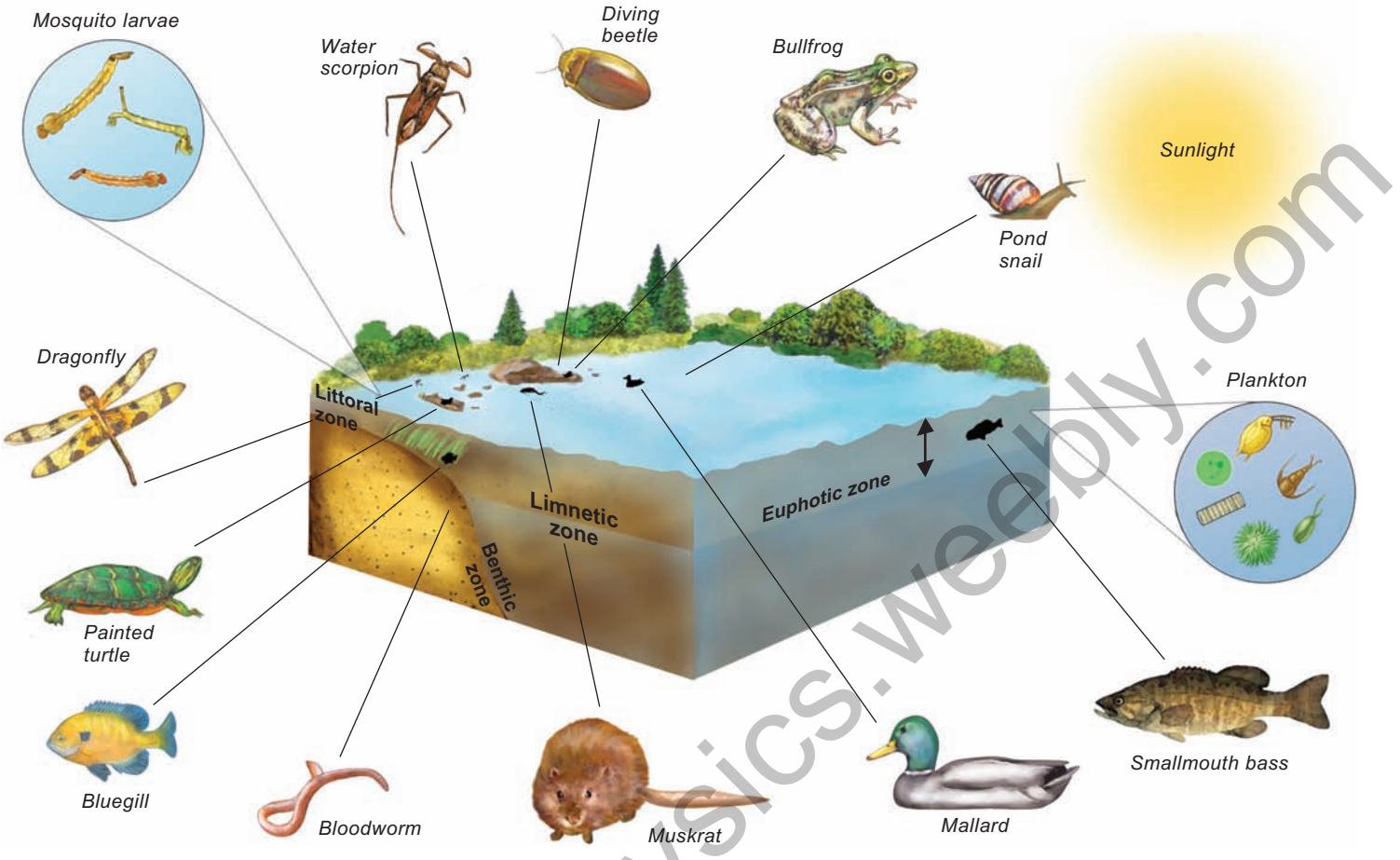


FIGURE 16.29 Lake Ecosystem
Lakes are similar in structure to oceans except that the species are different because most marine organisms cannot live in freshwater. Insects are common organisms in freshwater lakes, as are many kinds of fish, zooplankton, and phytoplankton.

Human Impact on Freshwater Ecosystems

Freshwater resources in lakes and rivers account for about 0.02% of the world's water. Most freshwater ecosystems have been heavily impacted by human activity. Any activity that takes place on land ultimately affects freshwater because of runoff from the land. Agricultural runoff, sewage, sediment, and trash all find their way to streams and lakes.

16.5 CONCEPT REVIEW

11. How do phytoplankton and zooplankton differ?
12. Describe how the producers of benthic and pelagic ecosystems differ.
13. List two ways in which the kinds of organisms present in lakes differ from those in shallow parts of the ocean.
14. Describe two abiotic differences between an estuary and the ocean.

16.6 Succession

Biomes consist of communities that are relatively stable over long periods of time. A relatively stable, long-lasting community is called a **climax community.** The word *climax* implies the final step in a series of events. That is just what the word means in this context, because communities can go through a series of predictable, temporary stages, which eventually result in a long-lasting, stable community. The process of changing from one type of community to another is called **succession,** and each intermediate stage leading to the climax community is known as a **successional stage** or **successional community.**

Scientists recognize two kinds of succession. **Primary succession** occurs when a community of plants and animals develops where none existed previously. **Secondary succession** occurs when a community of organisms is disturbed or destroyed by a natural or human-related event (e.g., a hurricane, volcano, fire, forest harvest, farming) and is returned to an earlier stage in the process of succession.

Primary Succession

Primary succession is much more difficult to observe than secondary succession because there are relatively few places on Earth that lack communities of organisms. The tops of mountains, newly formed volcanic rock, and rock newly exposed by erosion or glaciers can be said to lack life. However, bacteria, algae, fungi, and lichens quickly begin to grow on the bare rock surface, beginning the process of succession. The first organisms to colonize an area are often referred to as **pioneer organisms,** and the community is called a **pioneer community.**

Terrestrial Primary Succession

Lichens are frequently important in pioneer communities. They are unusual organisms consisting of a combination of algae cells and fungi cells—a very hardy combination that is able to grow on the surface of bare rock (figure 16.30). Because algae cells are present, the lichen is capable of photosynthesis and can form new organic matter. Furthermore, many tiny consumer organisms can use the lichen as a food source and a sheltered place to live. The lichen's action also tends to break down the rock surface on which it grows. This fragmentation of rock by lichens is aided by the physical weathering processes of freezing and thawing, dissolution by water, and wind erosion. Lichens also trap dust particles, small rock particles, and the dead remains of lichens and other organisms that live in and on lichens. These processes of breaking down rock and trapping particles result in the formation of a thin layer of soil.

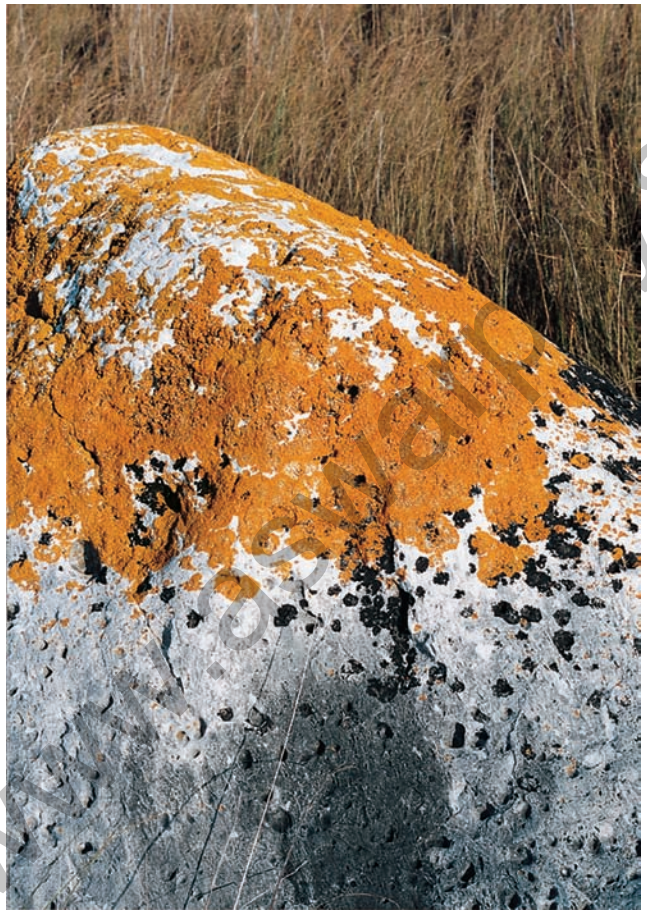


FIGURE 16.30 Pioneer Organisms
The orange or black lichens growing on rock begin the process of soil formation that is necessary for the development of later successional stages. They carry on photosynthesis, trap organic matter, and break down the surface of the rock.

As the soil layer becomes thicker, small plants, such as mosses, may become established, increasing the rate at which energy is trapped and adding more organic matter to the soil. Eventually, the soil may be able to support larger plants that are even more efficient at trapping sunlight, and the soil-building process continues at a more rapid pace. Associated with the producers in each successional stage are a variety of small animals, fungi, and bacteria. Each change in the community makes it more difficult for the previous group of organisms to maintain itself. Tall plants shade the smaller ones they replace; consequently, the smaller plants become less common, and some disappear entirely. Only shade-tolerant species are able to grow and compete successfully in the shade of the taller plants. As this takes place, one stage succeeds the other. Figure 16.31 summarizes these changes.

Depending on the physical environment and the availability of new colonizing species, succession from this point can lead to different kinds of climax communities. If the area is dry, it might stop at a grassland stage. If it is cold and wet, a coniferous forest might be the climax community. If it is warm and wet, it may become a tropical rainforest. The rate at which succession takes place is also variable. In some warm, moist, fertile areas, the entire process might take place in less than 100 years. In harsh environments, such as mountaintops and very dry areas, it may take thousands of years.

Aquatic Primary Succession

Primary succession also occurs in the progression from an aquatic community to a terrestrial community. Lakes, ponds, and slow-moving parts of rivers accumulate organic matter. Where the water is shallow, this organic matter supports the development of rooted plants. In deeper water, only plants with floating leaves, such as water lilies, send their roots down to the mucky bottom. In shallower water, upright, rooted plants, such as cattails and rushes, develop. As the plants contribute more organic matter to the bottom, the water level becomes shallower. Eventually, a mat of mosses, grasses, and even small trees may develop on the surface along the edge of the water. If this continues for perhaps 100 to 200 years, an entire pond or lake will become filled in. More organic matter accumulates because of the large number of producers and because the depression that was originally filled with water becomes drier. This usually results in a wet grassland, which in many areas is replaced by the climax forest community typical of the area (figure 16.32).

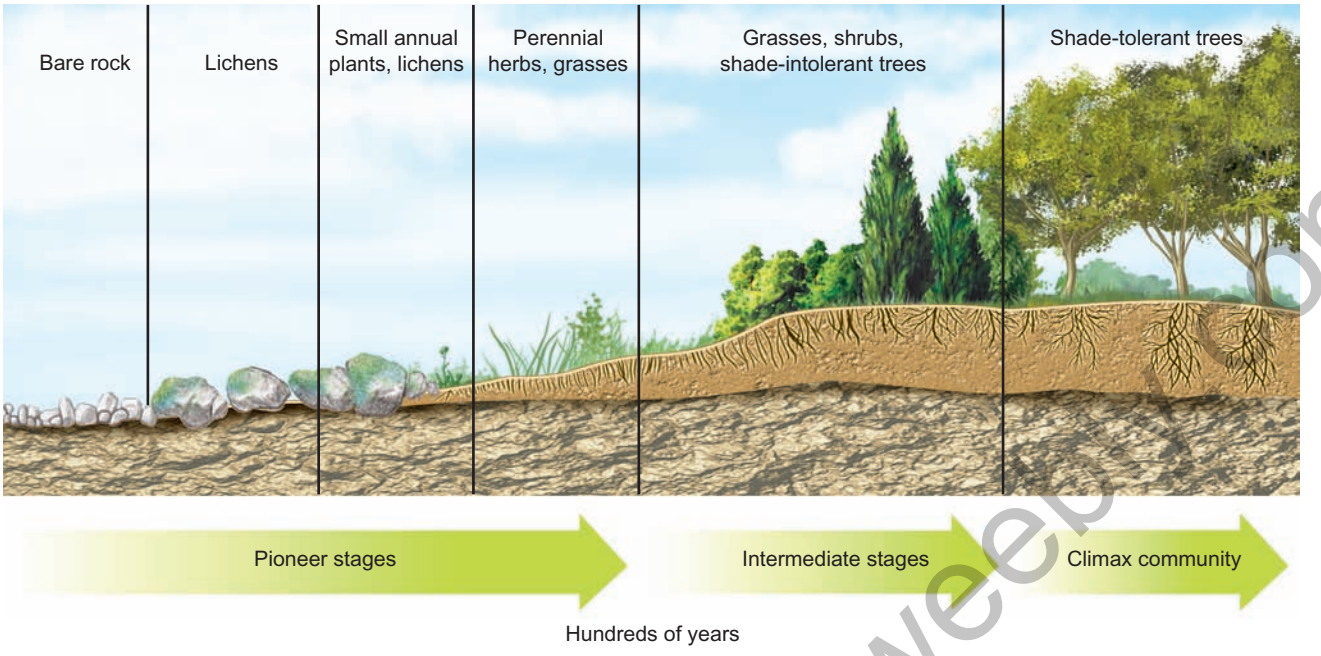


FIGURE 16.31 Primary Succession
The formation of soil is a major step in primary succession. Until soil is formed, the area is unable to support large amounts of vegetation. The vegetation modifies the harsh environment and increases the amount of organic matter that can build up in the area. As the kinds of plants change, so do the animals. As taller plants become established, the shorter plants that were part of earlier successional stages are eliminated. If given enough time, a climax community may develop.

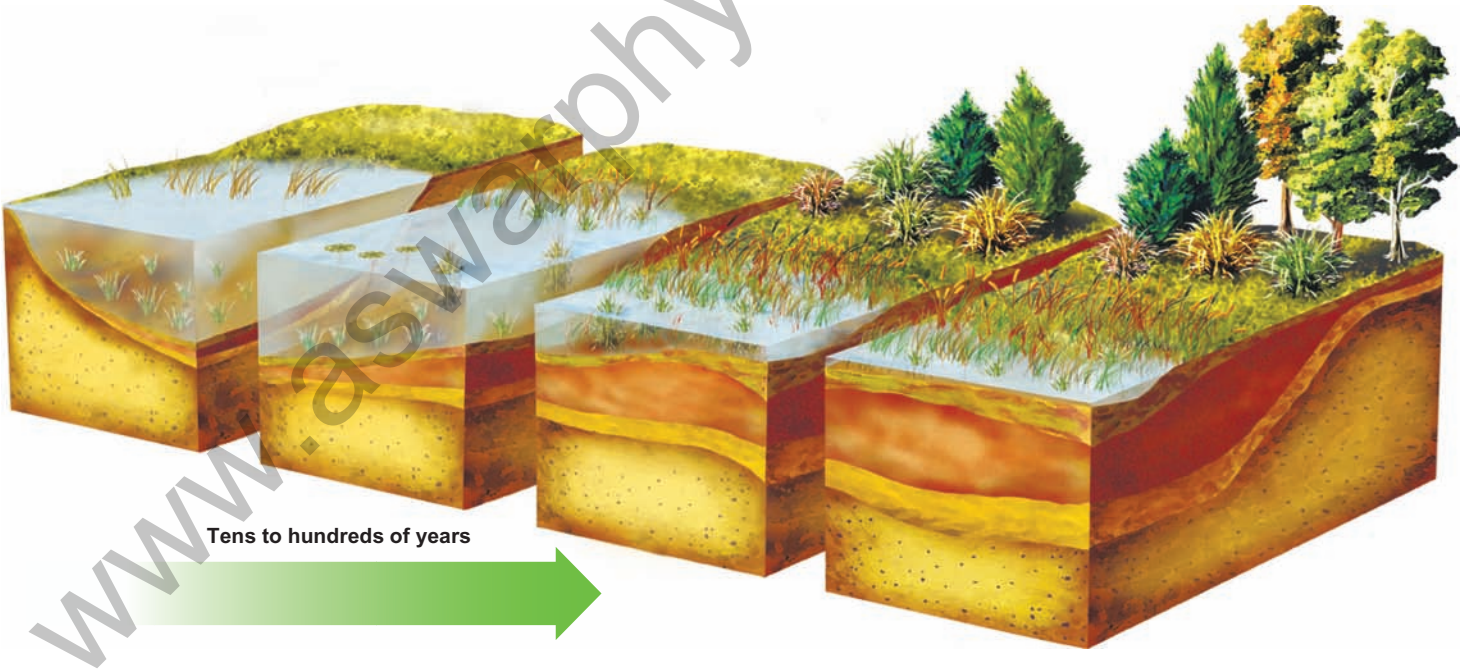


FIGURE 16.32 Succession from a Pond to a Wet Meadow
A shallow pond will slowly fill with organic matter from producers in the pond. Eventually, a floating mat will form over the pond and grasses will become established. In many areas, this will be succeeded by a climax forest.

Secondary Succession

Secondary succession occurs when a climax community is altered or destroyed by natural events or human activity. For example, when land is converted to agriculture, the original forest or grassland community is destroyed and replaced by crops. However, when agricultural land is abandoned, it returns to something like the original climax community. One obvious difference between primary succession and secondary succession is that, in secondary succession, there is no need to develop a soil layer. Another difference is that there is likely to be a reservoir of seeds from plants that were part of the original climax community. The seeds can survive in the soil for years in a dormant state, or they might be transported to the disturbed site from undisturbed sites nearby.

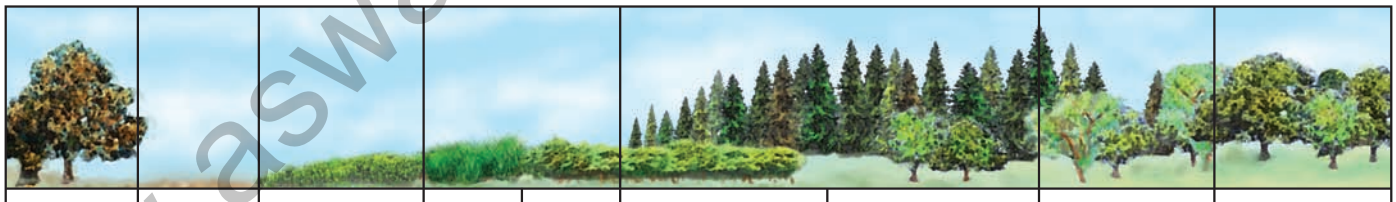
If we begin with bare soil the first year, it is likely to be invaded by a pioneer community of annual weed species. Within a year or two, perennial plants, such as grasses, become established. Because most of the weed species need bare soil for seed germination, they are replaced by the perennial grasses and other plants that live in association with grasses. The more permanent grassland community is able to support more insects, small mammals, and birds than the weed community could. In regions where rainfall is low, succession is likely to stop at this grassland stage. In regions with adequate rainfall, several species of shrubs and fast-growing trees that require lots of sunlight (e.g., birch, aspen, juniper, hawthorn, sumac, pine, spruce, and dogwood) become common. As the trees become larger, the grasses fail to get sufficient sunlight and die out. Eventually, shade-tolerant species of trees (e.g., beech, maple, hickory, oak, hemlock, and cedar) replace the shade-intolerant species, and a climax community results (figure 16.33).

Modern Concepts of Succession and Climax

The discussion of the nature of succession and climax communities in the Succession section is an oversimplification of the true nature of the process. Some historical perspective will help to clarify how ecologists have altered their concept of successional change. When European explorers traveled across the North American continent, they saw huge expanses of land dominated by specific types of communities: hardwood forests in the east, evergreen forests in the north, grasslands in central North America, and deserts in the southwest. These regional communities came to be considered the steady-state or normal situation for those parts of the world. When ecologists began to explore the way in which ecosystems developed over time, they began to think of these ecosystems as the end point or climax of a long journey, beginning with the formation of soil and its colonization by a variety of plants and other organisms.

As settlers removed the original forests or grasslands and converted the land to farming, the original "climax" community was destroyed. Eventually, as poor farming practices destroyed the soil, many farms were abandoned and the land was allowed to return to its "original" condition. This secondary succession often resulted in forests that resembled those that had been destroyed. However, in most cases, these successional forests contained fewer species and in some cases were entirely different kinds of communities from the originals. These new stable communities were also called climax communities, but they were not the same as the original climax communities.

In addition, the introduction of species from Europe and other parts of the world changed the mix of organisms that



Mature oak/hickory forest destroyed	Farmland abandoned	Annual plants	Grasses and biennial herbs	Perennial herbs and shrubs begin to replace grasses and biennials.	Pines begin to replace shrubs.	Young oak and hickory trees begin to grow.	Pines die and are replaced by mature oak and hickory trees.	Mature oak/hickory forest
		1–2 years	**3–4 years**	**4–15 years**	**5–15 years**	**10–30 years**	**50–75 years**	

FIGURE 16.33 Secondary Succession on Land
When agricultural land is abandoned, it goes through a series of changes. The general pattern is for annual weeds to become established in the first year or two following abandonment. These weeds are replaced by grasses and other perennial herbs, which are replaced by shrubs, which are replaced by trees. As the plant species change, so do the animal species.

might colonize an area. Many grasses and herbs that were introduced either on purpose or accidentally have become well established. Today, some communities are dominated by these introduced species. Even diseases have altered the nature of climax communities. Chestnut blight and Dutch elm disease have removed tree species that were at one time dominant species in certain plant communities.

Ecologists began to recognize that there was no fixed, predetermined community for each part of the world, and they began to modify the way they looked at the concept of climax communities. The concept today is a more plastic one. It is still used to talk about a stable stage following a period of change, but ecologists no longer feel that land will eventually return to a "preordained" climax condition. They have also recognized in recent years that the type of climax community that develops depends on many factors other than simply climate. One of these is the availability of seeds to colonize new areas. Some seeds may lie dormant in the soil for a decade or more, while others may be carried to an area by wind, water, or animals. Two areas with very similar climate and soil characteristics may develop very different successional and "climax" communities because of the seeds that were present in the area when the lands were released from agriculture.

Furthermore, we need to recognize that the only thing that differentiates a "climax" community from a successional one is the time scale over which change occurs. "Climax" communities do not change as rapidly as successional ones. However, all communities are eventually replaced, as were the swamps that produced coal deposits, the preglacial forests of Europe and North America, and the pine forests of the northeastern United States.

Many human activities alter the nature of the successional process. Agricultural practices obviously modify the original community to allow for the raising of crops. However, several other management practices have also significantly altered communities. Regular logging returns a forest to an earlier stage of succession. The suppression of fire in many forests has also changed the mix of organisms present. When fire is suppressed, those plants that are killed by regular fires become more common and those that are able to resist fire become less common. Changing the amount of water present will also change the kind of community. Draining an area makes it less suitable for the original inhabitants and more suitable for those that live in drier settings. Similarly, irrigation and flooding increase the amount of water present and change the kinds of organisms that can live in an area.

So what should we do with these concepts of succession and climax communities? Although the climax concept embraces a false notion that there is a specific end point to succession, it is still important to recognize that there is an identifiable, predictable pattern of change during succession and that later stages in succession are more stable and longer lasting than early stages. Whether we call a specific community of organisms a climax community is not really important.

Succession and Human Activity

Most agricultural use of ecosystems involves replacing the natural climax community with an artificial early successional stage. Therefore, it requires considerable effort on our part to prevent succession back to something like the original climax community. This is certainly true if remnants of the original natural community are still locally available to colonize agricultural land. Small woodlots in agricultural areas of the eastern United States serve this purpose. Much of the work and expense of farming (e.g., tilling, herbicides) is necessary to prevent succession to the natural climax community. It takes a lot of energy to fight nature.

Many human-constructed lakes and farm ponds have weed problems, because they are shallow and provide ideal conditions for the normal successional processes that lead to their being filled in. Often, humans do not recognize what a powerful force succession is.

16.6 CONCEPT REVIEW

15. How does primary succession differ from secondary succession?
16. How does a climax community differ from a successional community?
17. Describe the steps in the secondary succession of abandoned farmland to a climax community.
18. Describe the steps in the succession of a pond to a climax community.
19. Describe three important factors that determine the kind of climax community that will develop in an area.

16.7 The Impact of Human Actions on Communities

There is very little of the Earth's surface that has not been altered by human activity. Often, the changes we cause have far greater impact than we might think (How Science Works 16.1). All organisms are interlinked in a complex network of relationships. Therefore, before changing a community, it is wise to analyze how its organisms are interrelated. This is not always easy, because there is much we still do not know about how organisms interact and how they use molecules from their environment. Several lessons can be learned from studying the effects of human activity on communities.

Introduced Species

One of the most far-reaching effects humans have had on natural communities involves the introduction of foreign species. Many of these introductions have been conscious

HOW SCIENCE WORKS 16.1

Whole Ecosystem Experiments

Many environmental issues are difficult to resolve because, although there are hypotheses about what is causing a problem, the validity of the hypotheses has not been tested by experiments. Therefore, when governments seek to set policy, there are always those who argue that there is little hard evidence that the problem is real or that the cause of the problem has not been identified. Several examples include: What causes eutrophication of lakes? What causes acidification of lakes and rivers? What are the causes of global climate change? What is the likelihood that emissions from coal-fired power plants are causing increased in mercury in fish? The most powerful tests of hypotheses related to these problems are experiments that take place on a large scale in natural settings. Several such experiments have been crucial in identifying causes of environmental problems and led to policy changes that have alleviated environmental problems.

Beginning in 1966, the Canadian government established the Experimental Lakes Area in western Ontario. Many lakes were designated for experiments that would help answer questions about environmental issues. One experiment tested the hypothesis that phosphorus was responsible for eutrophication (excessive growth of algae and plants) of lakes. Laboratory studies had suggested that carbon, nitrogen, or phosphorus could be responsible. To help answer which of these three nutrients was the cause of eutrophication, a dumb-bell-shaped lake was divided in two at its narrow "waist" by placing a plastic curtain across the lake. One portion had carbon, nitrogen, and phosphorus added to it and the other portion had only carbon and nitrogen added. The results were clear. The portion of the lake with the added phosphorus had an abundant growth of algae and turned green. The other portion of the lake with carbon and nitrogen but no phosphorus did not (see photo). As a result of this experiment, governments were justified in requiring detergent manufacturers to remove phosphorous compounds from their products and requiring sewage treatment plants to eliminate phosphorus from their effluent.

Other experiments on whole lakes have investigated:

- The effects of acid deposition on food webs in lakes—predator fish starve as their prey disappear.
- The effects of flooding of land by dams—there is an increase in the mercury content of fish and carbon dioxide and methane are released into the atmosphere.
- The effects of removal of aquatic vegetation—northern pike populations declined.

After each experiment, the Canadian government requires that the lake be returned to its pristine condition.

decisions. Nearly all domesticated plants and animals in North America are introductions from elsewhere. Corn, beans, sunflowers, squash, and turkeys are exceptions. Cattle, horses, pigs, goats, and many introduced grasses have significantly altered the original communities present in the Americas. Cattle have replaced the original grazers on grasslands. Pigs have become a major problem in Hawaii and many other places in the world, where they destroy the natural community by digging up roots and preventing the reproduction of native plants. The introduction of grasses as food for cattle has resulted in the decline of many native species of grasses and other plants that were originally part of grassland communities. In Australia, the introduction of domesticated plants and animals—as well as wild animals, such as rabbits and foxes—has severely reduced the populations of many native marsupial mammals.

Accidental introductions have also significantly altered communities. Chestnut blight has essentially eliminated the American chestnut from the forests of eastern North America. Similarly, a fungal disease (Dutch elm disease) has severely reduced the number of elms. The accidental introduction of zebra mussels has significantly altered freshwater communities in eastern North America and has severely reduced the populations of native clams. Figure 16.34 shows two introduced species that have significantly altered communities in North America.

Dandelions

Mute swans

FIGURE 16.34 Introduced Species
Many introduced species become pests. Dandelions and mute swans are two examples.

Predator Control

Many kinds of large predators were actively destroyed to protect livestock. Predator control was also thought to be important in the management of game species. During the formative years of wildlife management, it was thought that populations of game species could be increased if the populations of their predators were reduced. For these reasons, many states passed laws to encourage the killing of foxes, eagles, hawks, owls, coyotes, cougars, and other predators that could kill livestock or use game animals as a source of food. Often, bounties were paid to people who killed these predators (figure 16.35).

The absence of predators can lead to many kinds of problems. In many metropolitan areas, deer have become pests. This is due to several reasons, including the fact that there are no predators, and hunting (predation by humans) either is not allowed or is impractical because of the highly urbanized nature of the area. Some municipalities have instituted programs of chemical birth control for their deer populations.

Only a few years ago, the alligator was on the endangered species list and all hunting was suspended. However, today increased numbers of alligators present a danger, particularly to pets and children. Hunting is now allowed in an effort to control the numbers of alligators, because humans are the only effective predators of large alligators.

Similarly, in Yellowstone National Park, elk, bison, and moose populations had become very large, because hunting is not allowed and predator populations had been small. In 1995, wolves were reintroduced to the park in the hope that they would help bring the elk and moose populations under control (figure 16.36). This was a controversial decision, however, because ranchers in the vicinity did not want a return of large predators that might prey on their livestock. They are also opposed to having bison, many of which carry a disease that can affect cattle, stray onto their land. The wolf population has increased significantly in Yellowstone and is having an effect on the populations of bison, elk, and moose. Regardless of the politics involved in the decision, Yellowstone is in a more natural condition today, with wolves present, than it was prior to 1995.

By contrast, the state of Alaska allows the hunting of wolves because many Alaskans believe the wolves are reducing caribou populations below optimal levels. Caribou hunting is an important source of food for Alaskan natives, and hunters who visit the state provide a significant source of income. Many groups oppose the killing of wolves in Alaska, however. They consider the policy misguided and believe it will not have a positive effect on the caribou population.

As wolf populations have increased in parts of the northern Rocky Mountains and the Great Lakes region, they have been removed from the federal endangered species list. Several states have re-established hunting seasons for wolves. The primary justification is to minimize the impact of wolf predation on livestock.

(a)

(b)

FIGURE 16.35 Predator Control
At one time, people were paid to kill various kinds of predators. *(a)* These men receive $35 for each wolf killed. *(b)* This coyote was killed and hung on a fence because it was considered a threat to livestock.

A captured Canadian wolf

Wolf in its habitat

FIGURE 16.36 The Reintroduction of Wolves to Yellowstone
In 1995, wolves were captured in Canada and moved to Yellowstone National Park to reestablish a wolf population. Now, there is a large, healthy wolf population in Yellowstone.

Habitat Destruction

Some communities are fragile and easily destroyed by human activity, whereas others seem able to resist human interference. Communities with a wide variety of organisms that show a high level of interaction are more resistant than are those with few organisms and little interaction. In general, the more complex a community, the more likely it is to recover after being disturbed. The tundra biome is an example of a community with relatively few organisms and interactions. It

is not very resistant to change and, because of its slow rate of repair, damage caused by human activity may persist for hundreds of years.

Some species are more resistant to human activity than are others. Rabbits, starlings, skunks, and many kinds of insects and plants are able to maintain high populations despite human activity. Indeed, some may even be encouraged by human activity. By contrast, whales, condors, eagles, and many plant and insect species are not able to resist human interference very well. For most of these endangered species, it is not humans' acting directly with the organisms that cause their endangerment. Very few organisms have been driven to extinction by hunting or direct exploitation. Usually, the cause of extinction or endangerment is an indirect effect of habitat destruction as humans exploit natural communities. As humans convert land to farming, grazing, commercial forestry, development, and special wildlife management areas, natural communities are disrupted, and plants and animals with narrow niches tend to be eliminated, because they lose critical resources in their environment. Figure 16.37 shows various kinds of habitat destruction, and table 16.3 lists eight endangered and threatened species and the probable causes of their difficulties.

Pesticide Use

Humans have developed a variety of chemicals to control specific pests. These chemicals have a variety of names. *Herbicides* are used to kill plants. *Insecticides* are used to kill insects. *Fungicides* are used to kill fungi. Often, all these kinds of chemicals are lumped together into one large category—*pesticides*—because they are used to control various kinds of pests. Although various kinds of pesticides are valuable in controlling disease in human and domesticated animal populations and in controlling pests in agriculture, they have some negative community effects as well.

One problem associated with continual pesticide use is that pests become resistant to these chemicals. When a pesticide is used, most of the pests are killed. However, some may be able to resist its effects. When these survivors reproduce, they pass on their genes for resistance to their offspring, and the next generation is less susceptible to the pesticide. Ultimately, resistant populations develop and the pesticide is no longer useful.

Another problem associated with pesticide use is the effects they have on valuable nontarget organisms. Insecticides typically kill a wide variety of organisms other than the targeted pest species. Often, other species in the community have a role in controlling pests. Predators kill pests and parasites use them as hosts. Generally, predators and parasites reproduce more slowly than their prey or host species. Because of this, the use of a nonspecific insecticide may indirectly make controlling a pest more difficult. If such an insecticide is applied to an area, the pest is killed, but so are its predators and parasites. Because the herbivore pest reproduces faster than its predators and parasites, the pest population rebounds quickly, unchecked by natural predation and parasitism (figure 16.38).

Urban development

Conversion to agriculture

Logging

FIGURE 16.37 Habitat Destruction
Habitat destruction by the building of cities, conversion of land to agriculture, and commercial forest practices has a major impact on the kinds of organisms that can survive in our world.

Today, a more enlightened approach to pest control is *integrated pest management,* which uses a variety of approaches to reduce pest populations. Integrated pest management includes the use of pesticides as part of a pest control program, but it also includes strategies such as encouraging the natural

TABLE 16.3 Endangered and Threatened Species

Species	Reason for Endangerment
Hawaiian crow (*Corvis hawaiinsis*)	Predation by introduced cat and mongoose, disease, habitat destruction
Sonora chub (*Gila ditaenia*)	Competition with introduced species in streams in Arizona and Mexico
Black-footed ferret (*Mustela nigripes*)	The poisoning of prairie dogs (their primary food)
Snail kite (*Rostrhamus sociabilis*)	Specialized eating habits (they eat only apple snails), the draining of marshes in Florida
Grizzly bear (*Ursus arctos*)	The loss of wilderness areas
California condor (*Gymnogyps californianus*)	Slow breeding, lead poisoning
Ringed sawback turtle (*Graptemys oculifera*)	The modification of habitat by the construction of a reservoir in Mississippi that reduced their primary food source
Scrub mint (*Dicerandra frutescens*)	The conversion of their habitat to citrus groves and housing in Florida

Preparing an herbicide mixture

Aerial application of pesticide

FIGURE 16.38 Pesticide Use
Pesticides are used to control pests that injure or compete with crops and domesticated animals. Their use has several effects on the communities of plants and animals where they are used.

enemies of pests, changing farming practices to discourage pests, changing the mix of crops grown, and accepting low levels of crop damage as an alternative to costly pesticide applications.

Biomagnification

The use of persistent chemicals has an effect on the food chain. Chemicals that do not break down are passed from one organism to the next, and organisms at higher trophic levels tend to accumulate larger amounts than the organisms they feed on. This situation is known as **biomagnification.**

The history of DDT use illustrates the problems associated with persistent organic molecules. DDT was a very effective insecticide because it was extremely toxic to insects but not very toxic to birds and mammals. It is also a very stable compound, which means that, once applied, it remained effective for a long time. However, when an aquatic area was sprayed with a small concentration of DDT, many kinds of organisms in the area can accumulate tiny quantities in their bodies. Because marshes and other wet places are good mosquito habitats, these areas were often sprayed to control these pests. Even algae and protozoa found in aquatic ecosystems accumulate persistent pesticides. They may accumulate concentrations in their cells that are 250 times more concentrated than the amount sprayed on the ecosystem. The algae and protozoa are eaten by insects, which in turn are eaten by frogs, fish, and other carnivores.

The concentration in frogs and fish may be 2,000 times the concentration sprayed. The birds that feed on the frogs and fish may accumulate concentrations that are as much as 80,000 times the original amount. Because DDT is relatively stable and is stored in the fat deposits of the organisms that take it in, what was originally a dilute concentration becomes more concentrated as it moves up the food chain (figure 16.39).

Before DDT use was banned in the United States in 1972, many animals at higher trophic levels died as a result of lethal concentrations of the pesticide accumulated from the food they ate. Each step in the food chain accumulated some DDT; therefore, higher trophic levels had higher concentrations. Even if they were not killed directly by DDT, many birds at higher trophic levels, such as eagles, pelicans, and osprey, suffered reduced populations. This occurred because the DDT

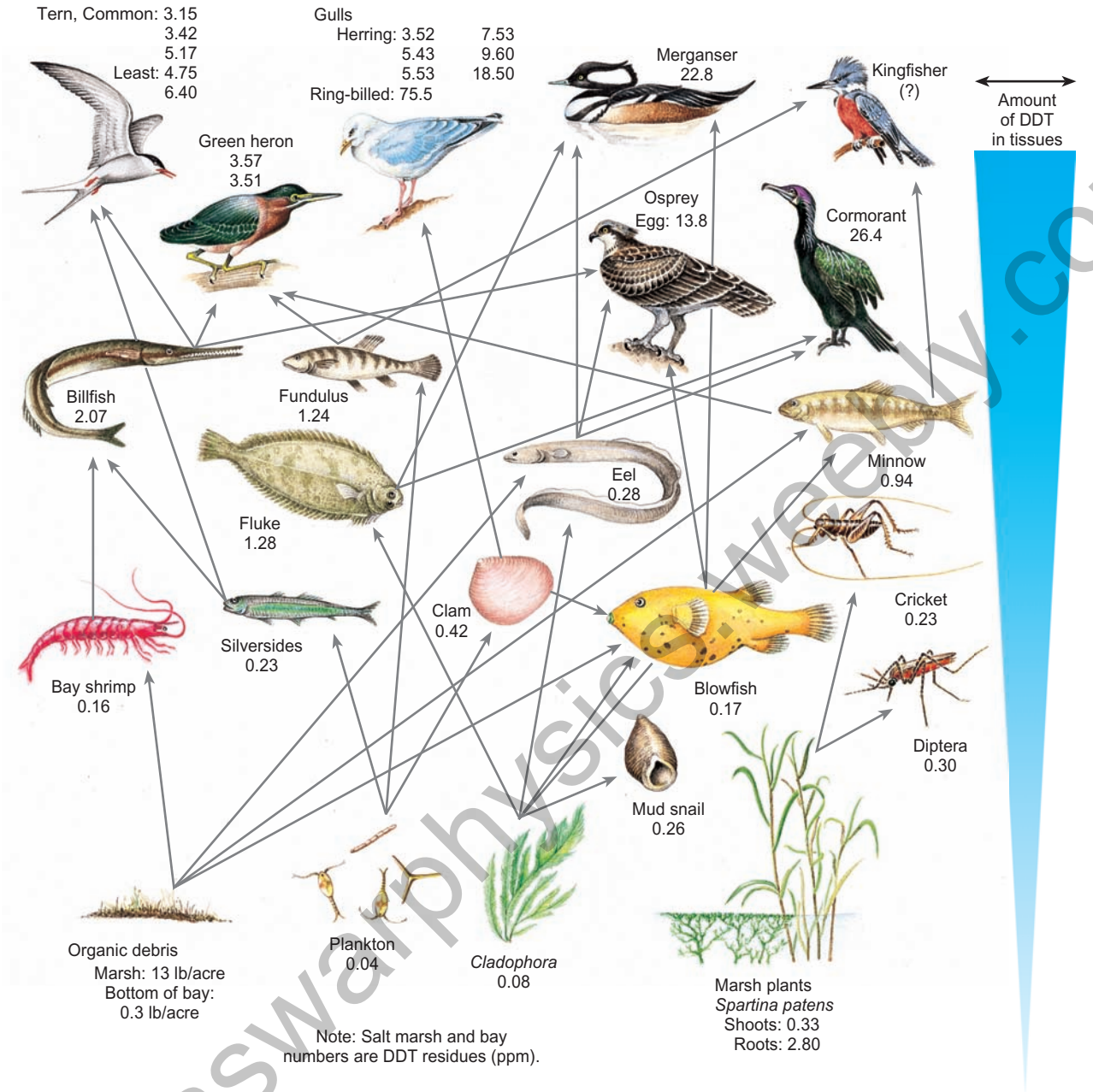


FIGURE 16.39 The Biomagnification of DDT
All the numbers shown are in parts per million (ppm). A concentration of one part per million means that, in a million equal parts of the organism, one of the parts would be DDT. Notice how the amount of DDT in the bodies of the organisms increases from producers to herbivores to carnivores. Because DDT is persistent, it builds up in the top trophic levels of the food chain.

interfered with the female birds' ability to produce eggshells. Thin eggshells are easily broken; thus, no live young hatched. Both the bald eagle and the brown pelican were placed on the endangered species list because their populations had dropped dramatically as a result of DDT poisoning. The ban on DDT use in the United States and Canada has resulted in an increase in the populations of both kinds of birds. Because the populations have recovered, the bald eagle was removed from the endangered species list in 2007 and the brown pelican in 2009.

Several other chemical compounds are also of concern today because they are biomagnified in food chains. These include polychlorinated biphenyls (PCBs), dioxins, methylmercury, and many other compounds. Because these compounds can reach high concentrations in fish that are at the top of the food chain, many states and countries publish advisories that caution people not to eat large quantities of these fish. When the production of PCBs was halted in 1979, the level of contamination in fish declined.

16.7 CONCEPT REVIEW

20. Why do DDT and PCBs increase in concentration in the bodies of organisms at higher trophic levels?
21. What is the most common form of habitat destruction practiced by humans?
22. List three introduced species that have become pests, and explain why they became pests.
23. What happens to a community of organisms when predators are eliminated?
24. Describe two negative consequences of using pesticides.

Summary

Each organism in a community occupies a specific space, known as its habitat, and has a specific functional role to play, known as its niche. An organism's habitat is usually described in terms of a conspicuous element of its surroundings. The niche is difficult to describe, because it involves so many interactions with the physical environment and other living things.

Interactions between organisms fit into several categories. Predation is one organism benefiting (predator) at the expense of the organism killed and eaten (prey). Parasitism is one organism benefiting (parasite) by living in or on another organism (host) and deriving nourishment from it. Organisms that carry parasites from one host to another are called vectors. Commensal relationships exist when one organism is helped but the other is not affected. Mutualistic relationships benefit both organisms. Symbiosis is any interaction in which two organisms live together in a close physical relationship. Competition causes harm to both of the organisms involved, although one may be harmed more than the other and may become extinct, evolve into a different niche, or be forced to migrate.

A community consists of the interacting populations of organisms in an area. The organisms are interrelated in many ways in food chains, which interlock to create food webs. Because of this interlocking, changes in one part of the community can have effects elsewhere.

Major land-based regional communities are known as biomes. The temperate deciduous forest, boreal coniferous forest, tropical rainforest, temperate grassland, desert, savanna, temperate rainforest, and tundra are biomes.

Aquatic ecosystems can be divided into marine and freshwater systems. Several kinds of marine ecosystems are: pelagic, benthic, coral reef, abyssal, and shoreline ecosystems. Freshwater ecosystems are generally separated into streams and rivers in which the water is running downhill and lakes and ponds in which it is not.

Communities go through a series of predictable changes that lead to a relatively stable collection of plants and animals. This process of change is called succession, and the resulting stable unit is called a climax community.

Organisms within a community are interrelated in sensitive ways; thus, changing one part of a community can lead to unexpected consequences. The introduction of foreign species, predator-control practices, habitat destruction, pesticide use, and biomagnification of persistent toxic chemicals all have caused unanticipated changes in communities.

Key Terms

Use the interactive flash cards on the ***Concepts in Biology****, 14/e website to help you learn the meaning of these terms.*

abyssal ecosystem 358
benthic 357
benthic ecosystem 357
biomagnification 369
biomes 343
climax community 360
commensalism 340
competition 336
competitive exclusion principle 337
coral reef ecosystem 358
epiphytes 340
estuary 358
euphotic zone 356
external parasites 338
food web 333
habitat 334
host 338
internal parasites 338
interspecific competition 336
intraspecific competition 336
limnetic zone 359
littoral zone 359
mutualism 341
niche 334
parasite 338
parasitism 338
pelagic 356
pelagic ecosystem 356
phytoplankton 356
pioneer community 361
pioneer organisms 361
plankton 356
predation 337
predator 337
prey 337
primary succession 360
secondary succession 360
succession 360
successional stage (successional community) 360
symbiosis 338
vector 339
zooplankton 356

Basic Review

1. The role an organism plays in its surroundings is its
   a. niche.
   b. habitat.
   c. community.
   d. food web.
2. The kind of interrelationship between two organisms in which both are harmed is _____.

3. A desert is always characterized by
   a. high temperature.
   b. low amounts of precipitation.
   c. few kinds of plants and animals.
   d. sand.
4. When a community is naturally changing with the addition of new species of organisms and the loss of others, _____ is occurring.
5. When two organisms cooperate and both derive benefit from the relationship, it is known as commensalism. (T/F)
6. Most of the plants and animals involved in agriculture are introduced from other parts of the world. (T/F)
7. A biome that has trees adapted to long winters is known as a
   a. tundra.
   b. temperate deciduous forest.
   c. boreal coniferous forest.
   d. temperate rainforest.
8. If a forest is destroyed by a fire, it will eventually return to being a forest. This process is known as _____ succession.
9. A collection of organisms that interact with one another in an area is known as a
   a. community.
   b. biome.
   c. succession.
   d. biomagnification.
10. The idea that no two organisms can occupy the same niche is known as the competitive exclusion principle. (T/F)
11. The tundra biome has permafrost. (T/F)
12. Plankton organisms are strong swimmers. (T/F)
13. Which of the following organisms are common in freshwater ecosystems and rare in marine ecosystems?
    a. algae
    b. fish
    c. zooplankton
    d. insects
14. Which of the following have resulted in reductions in species native to an ecosystem?
    a. introduced species
    b. habitat destruction
    c. pesticide use
    d. all of the above
15. In marine ecosystems, pelagic organisms are located on the bottom. (T/F)

Answers

1. a 2. competition 3. b 4. succession 5. F 6. T 7. c 8. secondary 9. a 10. T 11. T 12. F 13. d 14. d 15. F

Thinking Critically

Natural and Managed Ecosystems

Farmers are managers of ecosystems. Consider a cornfield in Iowa. Describe five ways in which the cornfield ecosystem differs from the original prairie it replaced. At what trophic level does the farmer exist?

CHAPTER 17

Population Ecology

White-tailed Deer Are Becoming Urban Pests

Residents look for solutions.

CHAPTER OUTLINE

Many urban areas in eastern North America have a white-tailed deer population problem. Suburban areas with parks, nature preserves, and large lots are particularly hard-hit. The deer eat shrubs and other plantings in parks and in the yards of homes. Car-deer collisions result in millions of dollars of damage yearly and many human and deer deaths. In some areas there is concern about the role deer play in the spread of lyme disease.

Biologists point out that large urban deer populations are a case of "nature out of balance." There are few predators of deer in these areas and hunting is not allowed. So, with low mortality, populations have increased greatly. In more rural areas, there is some natural predation and hunters also play the role of predators.

There are few options to alleviate the problem. Currently, the administration of birth control measures to female deer is too expensive and difficult to achieve. Removal by trapping is expensive and has the additional problem of finding a suitable place to release the deer. Some cities have trapped deer and slaughtered them. More and more metropolitan areas have come to the conclusion that the most cost-effective method of population control is to allow controlled hunting or to hire specially trained sharpshooters to harvest deer. This is particularly effective in lowering populations if the females and young are harvested. In addition, the meat from the deer harvest is often donated to organizations that provide emergency food aid to local residents.

- **What conditions allow these populations to become so large that they become a public nuisance and cause serious economic damage?**
- **If increased mortality is not allowed, what methods could be used to reduce the number of births?**
- **Should cost be an issue in choosing the method used to control these populations?**

Background Check

Concepts you should already know to get the most out of this chapter:

- The difference between sexual and asexual reproduction (chapter 9)
- Organisms acquire matter and energy from their surroundings (chapter 16)
- Organisms change their surroundings (chapter 16)

17.1 Population Characteristics

A **population** is a group of organisms of the same species located in the same place at the same time. Examples are the dandelions in a yard, the rat population in your city sewer, and the number of students in a biology class. On a larger scale, all the people of the world constitute the world human population.

The terms *species* and *population* are interrelated, because a species is a population—the largest possible population of a particular kind of organism. The term *population,* however, is often used to refer to portions of a species by specifying a space and time. For example, the size of the human population in a city changes from hour to hour during the day and varies according to the city's boundaries. Because each local population is a small portion of its species, and each population is adapted to its local conditions, it is common that local populations differ from one another in the characteristics they display.

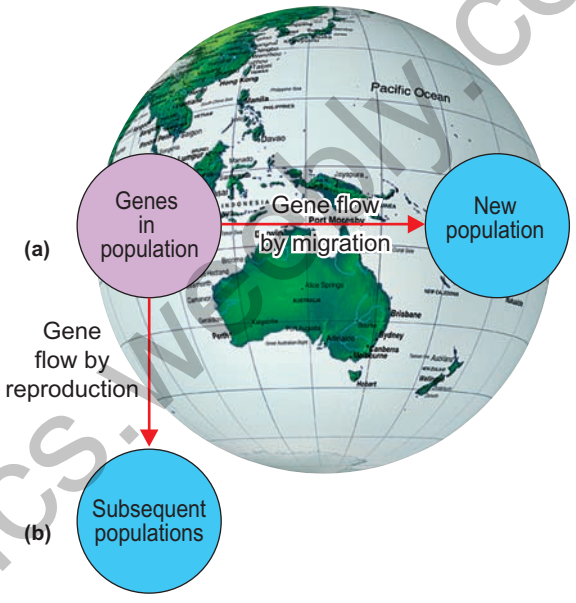


FIGURE 17.1 Gene Flow
Gene flow within a species occurs in two ways. *(a)* Genes flow from place to place when organisms migrate. *(b)* Genes flow from generation to generation as a result of reproduction.

Gene Flow and Gene Frequency

Recall from chapter 12 that a species is a group of organisms capable of interbreeding and producing fertile offspring. Thus, within a species, genes flow from one generation to the next through reproduction. In addition to gene flow from one generation to the next, genes also can flow from one place to another as organisms migrate or are carried from one locality to another. Typically, both kinds of gene flow happen together as individuals migrate to new regions and reproduce, passing on their genes to the next generation in the new area (figure 17.1).

As genes flow from generation to generation by reproduction or from one location to another by migration, it is possible that separate populations may develop differences in the frequency of specific genes. For example, many populations of bacteria have high frequencies of antibiotic-resistance genes whereas others do not. Methicillin-resistant *Staphylococcus aureus* (MRSA) has become a serious health problem, since this strain (population) of bacterium is resistant to methicillin and many other similar antibiotics. Populations of this strain of *S. aureus* are most common in hospitals and other health-care facilities. The frequency of the genes for tallness in humans is greater in certain African tribes than in any other human population. The frequency of the allele for type B blood differs significantly from one human population to another (figure 17.2).

Age Distribution

Age distribution is the number of organisms of each age in a population (figure 17.3). Often, organisms are grouped into three general categories based on their reproductive status:

1. Prereproductive juveniles (e.g. insect larvae, plant seedlings, and babies)
2. Reproductive adults (e.g. mature insects, plants producing seeds, and humans in early adulthood)
3. Postreproductive adults no longer capable of reproduction (e.g. annual plants that have shed their seeds, salmon that have spawned, and many elderly humans)

A population does not necessarily have an age distribution that is divided into equal thirds. Some populations are made up of a majority of one age group (figure 17.4).

Many populations of organisms that live only a short time have high reproductive rates. Thus, they have population

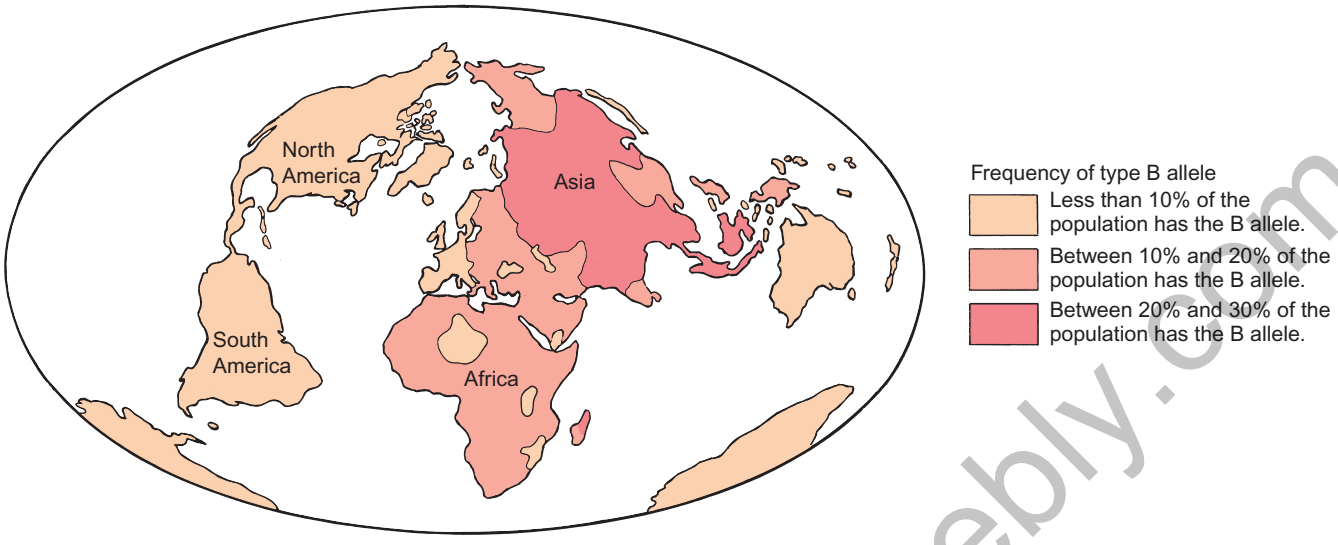


FIGURE 17.2 Distribution of the Allele for Type B Blood
The allele for type B blood is not evenly distributed in the world. This map shows that the type B allele is most common in parts of Asia and has been dispersed to the Middle East and parts of Europe and Africa. There has been very little flow of the allele to the Americas.

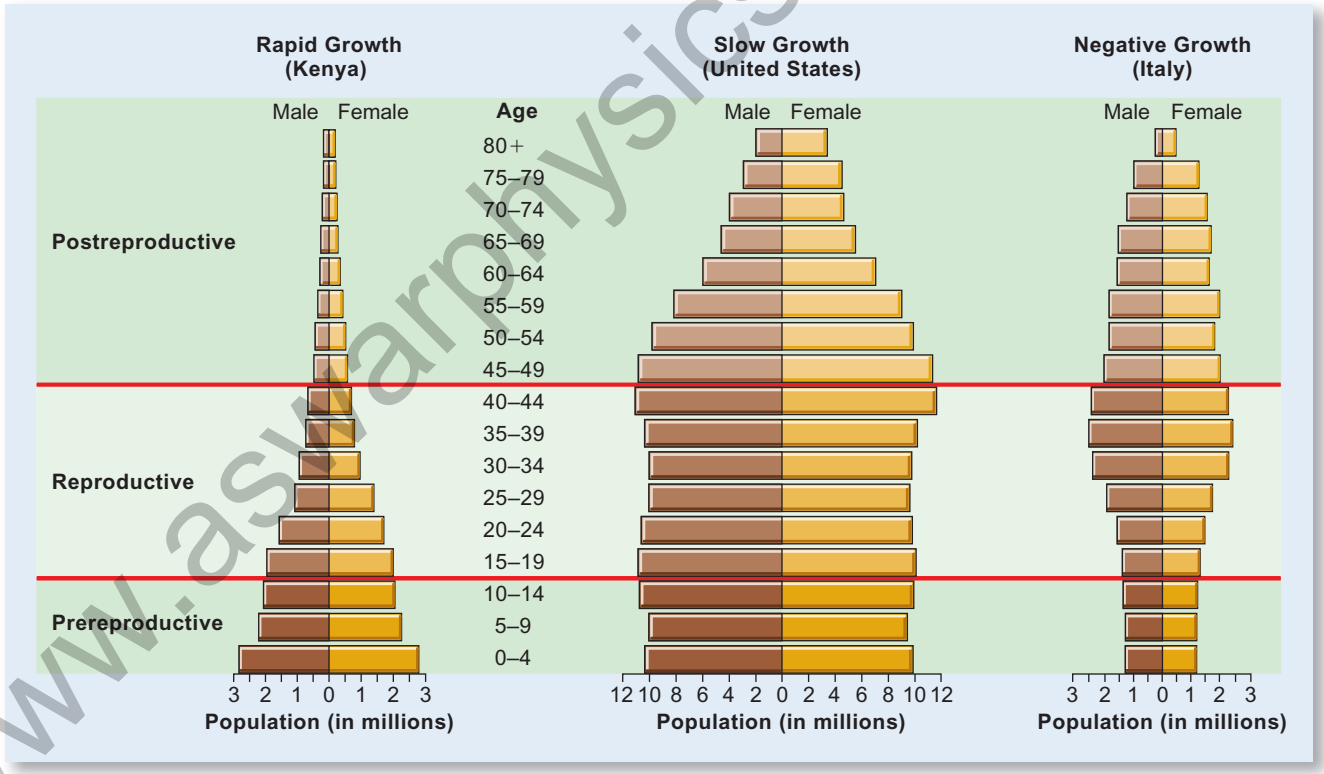


FIGURE 17.3 Age Distribution in Human Populations
The relative numbers of individuals in each of the three categories (prereproductive, reproductive, and postreproductive) are good clues to the future growth of a population. Kenya has a large number of young individuals who will become reproducing adults. Therefore, this population is likely to grow rapidly. The United States has a large proportion of reproductive individuals and a moderate number of prereproductive individuals. Therefore, this population is likely to grow slowly. Germany has a declining number of reproductive individuals and a very small number of prereproductive individuals. Therefore, its population has begun to decline.

Caterpillars

Sheep

Bladderpod

FIGURE 17.4 Age Distribution in Selected Populations
Some populations are composed of many individuals of the same general age. The caterpillars are a population of prereproductives. The flock of sheep has a small number of reproductive adults and a large number of prereproductive juveniles. The population of yellow bladderpod plants is dominated by reproductive adults.

age distributions that change significantly in a matter of weeks or months. For example, many birds have a flurry of reproductive activity during the summer months. Therefore, samples of the population of a particular species of bird at different times during the summer would show widely different proportions of reproductive and prereproductive individuals. In early spring before they have started to nest, all the birds are reproductive adults. In late spring through midsummer, there is a large proportion of prereproductive juveniles.

Similarly, in the spring, annual plants germinate from seeds and begin to grow—all of the individuals are prereproductive juveniles. Later in the year, all the plants flower—they become reproducing adults. Finally, all the plants become postreproductive adults and die. But they have left behind seeds—prereproductive juveniles—which will produce the next generation.

Age distribution can have a major effect on how the population grows. If most of the population is prereproductive, a rapid increase in its size can be anticipated in the future as the prereproductive individuals reach sexual maturity. If most of the population is reproductive, the population should be growing rapidly. If most of the population is postreproductive, a population decline can be anticipated.

Sex Ratio

The **sex ratio** of a population is the number of males in a population compared with the number of females. In many kinds of animals, such as bird and mammal species in which strong pair-bonding occurs, the sex ratio may be nearly 1 to 1 (1:1). Among mammals and birds that do not have strong pair-bonding, sex ratios may show a larger number of females than males. This is particularly true among game species in which more males than females are shot. This hunting practice leads to a higher proportion of surviving females. Because one male can fertilize several females, the population can remain large even though the females outnumber the males. In addition to these examples, many species of animals, such as bison, horses, elk, and sea lions, have mating systems in which one male maintains a harem of females. The sex ratio in these small groups is quite different from a 1:1 ratio (figure 17.5).

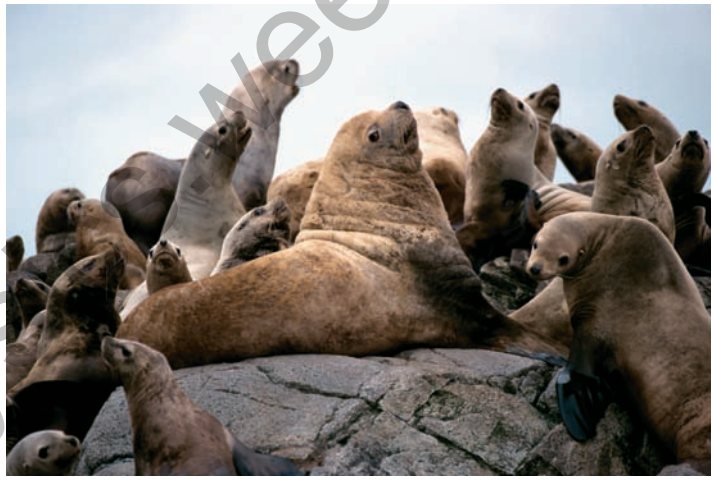


FIGURE 17.5 Sex Ratio
In some species of animals, males defend a harem of females; therefore, the sex ratio in these groups is several females per male. This male Steller sea lion is defending a harem of several females.

In many kinds of insect populations, such as bees, ants, wasps, and termites, there are many more females than males. Generally, in a colony of these organisms there is one or a few reproductive females, a large number of worker females, and very few males.

There are very few situations in which the number of males exceeds the number of females. In some human and other populations, there may be sex ratios in which the males dominate if female mortality is unusually high or if a special mechanism separates most of one sex from the other.

Many kinds of animals and plants are hermaphroditic, having both kinds of sex organs in the same body (e.g. earthworms and many flowering plants). Thus, the concept of sex ratio does not apply to them. Also, some species of animals—oysters, some fish, and others—change their sex at different times of their lives. They spend part of their lives as males and part as females.

Population Distribution

Population distribution is the way individuals within a population are arranged with respect to one another. There are basically three kinds of arrangements: even, random, and clumped. Even distributions occur under circumstances in which the organisms arrange themselves by very specific rules. In many birds that form dense breeding colonies, each nest is just out of reach of the neighbors. Random distributions are typical for many kinds of organisms that do not form social groups and have widely dispersed individuals. Many plants—particularly those that have seeds that are distributed by wind—have random distribution. Clumped distributions are typical for many kinds of plants and animals. In plants that have large seeds, the seeds are likely to fall near the parent plant and a clumped distribution results. In addition, plants that reproduce asexually produce local collections of organisms. Animals that form family groups, social groups, herds, or flocks typically show clumped distributions as do organisms that congregate near valuable resources, such as food or water (figure 17.6).

Even

Random

Clumped

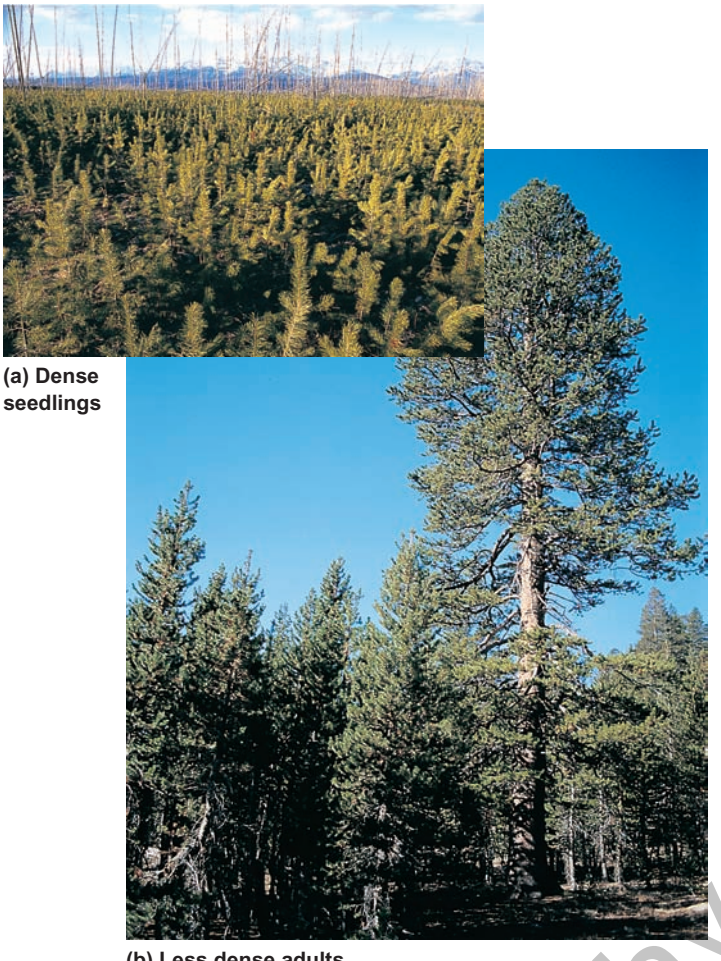
FIGURE 17.6 Population Distribution
The way organisms are distributed in their habitat varies. A few are evenly distributed. Some are randomly distributed. Many show some degree of clumped distribution.

Population Density

Population density is the number of organisms of a species per unit area. For example, the population density of dandelions in a park can be measured as the number of dandelions per square meter; the population density of white-tailed deer can be measured as the number of deer per square kilometer. Depending on the reproductive success of individuals in the population and the resources available, the density of populations can vary considerably. Some populations are extremely concentrated in a limited space; others are well dispersed. As reproduction occurs, the population density increases, which leads to increased competition for the necessities of life. Intense competition in dense populations is likely to lead to the death of some individuals and dispersal of individuals into less-populated areas.

Population pressure is the concept that increased intensity of competition, resulting from increased population size, causes changes in the environment and leads to the dispersal of individuals to new areas or the death of some individuals. Dispersal can relieve the pressure on the home area and lead to the establishment of new populations. Among animals, it is often the juveniles that participate in dispersal. For example, female bears generally mate every two years and abandon their nearly grown young the summer before the next set of cubs is to be born. The abandoned young bears tend to wander and disperse to new areas. Similarly, young turtles, snakes, rabbits, and many other common animals disperse during certain times of the year. That is one of the reasons so many animals are killed on the roads in the spring and fall.

If dispersal cannot relieve population pressure, there is usually an increase in the rate at which individuals die because of predation, parasitism, starvation, and accidents. For example, plants cannot relieve population pressure by dispersal. Instead, the death of weaker individuals usually results in reduced population density, which relieves population pressure. Following a fire, large numbers of lodgepole



(a) Dense seedlings

(b) Less dense adults

FIGURE 17.7 Changes in Population Density *(a)* This population of lodgepole pine seedlings consists of a large number of individuals very close to one another. *(b)* As the trees grow, many of the weaker trees will die, the distance between individuals will increase, and the population density will be reduced.

pine seeds germinate. The young seedlings form dense thickets of young trees. As the stand ages, many small trees die and the remaining trees grow larger as the population density drops (figure 17.7).

17.1 CONCEPT REVIEW

1. Describe two ways that gene flow occurs.
2. Give an example of a population with a high number of prereproductive individuals and another with a high number of reproductive individuals.
3. Describe two situations that can lead to a clumped distribution of organisms.
4. How is population pressure related to population density?

17.2 Reproductive Capacity

Sex ratios and age distributions within a population have a direct bearing on the rate of reproduction. A population's **reproductive capacity,** or **biotic potential,** is the theoretical number of offspring that could be produced. Some species produce huge numbers of offspring, whereas others produce few per lifetime. In some cases, the reproductive capacity is generally much larger than the number of offspring needed simply to maintain the population. For example, a female carp may produce 1 million to 3 million eggs in her lifetime; this is her reproductive capacity. However, only two or three of these offspring ever develop into sexually mature adults. Therefore, her reproductive rate is two or three offspring per lifetime and is much smaller than her reproductive capacity.

In general, there are two strategies for assuring that there will be enough offspring that live to adulthood to ensure the continuation of the species. One strategy is to produce huge numbers of offspring but not provide any support for them. For example, an oyster may produce a million eggs a year, but not all of them are fertilized, and most that are fertilized die. An apple tree with thousands of flowers may produce only a few apples because the pollen that contains the sperm cells was not transferred to the female part of each flower in the process of pollination. Even after offspring are produced, mortality is usually high among the young. Most seeds that fall to the Earth do not grow, and most young animals die. Usually, however, enough survive to ensure the continuance of the species. Organisms that reproduce in this way spend large amounts of energy on the production of gametes and young, but no energy caring for the young. Thus, the probability that any individual will reach reproductive age is small.

The second way of approaching reproduction is to produce relatively fewer individuals but provide care and protection, which ensures a higher probability that the young will become reproductive adults. Humans generally produce a single offspring per pregnancy, but nearly all of them live. In effect, with this strategy, energy has been channeled into the care and protection of the young, rather than into the production of incredibly large numbers of potential young. Even though fewer young are produced by animals such as birds and mammals, their reproductive capacity still greatly exceeds the number required to replace the parents when they die.

17.2 CONCEPT REVIEW

5. In what way do the activities of species that produces few young differ from those that produce huge numbers of offspring?
6. How does reproductive capacity compare to the reproductive rate?

17.3 The Population Growth Curve

Because most species have a high reproductive capacity, populations tend to grow if environmental conditions permit. The change in the size of a population depends on the rate at which new organisms enter the population, compared with the rate at which they leave. **Natality** is the number of individuals added to the population by reproduction per thousand individuals in the population. **Mortality** is the number of individuals leaving a population by death per thousand individuals in the population. If a species enters a previously uninhabited area, its population will go through a typical pattern of growth. Figure 17.8 shows a **population growth curve,** which is a graph of change in population size over time. There are four recognizable portions in a population growth curve: the *lag phase,* the *exponential growth phase,* the *deceleration phase,* and the *stable equilibrium phase.*

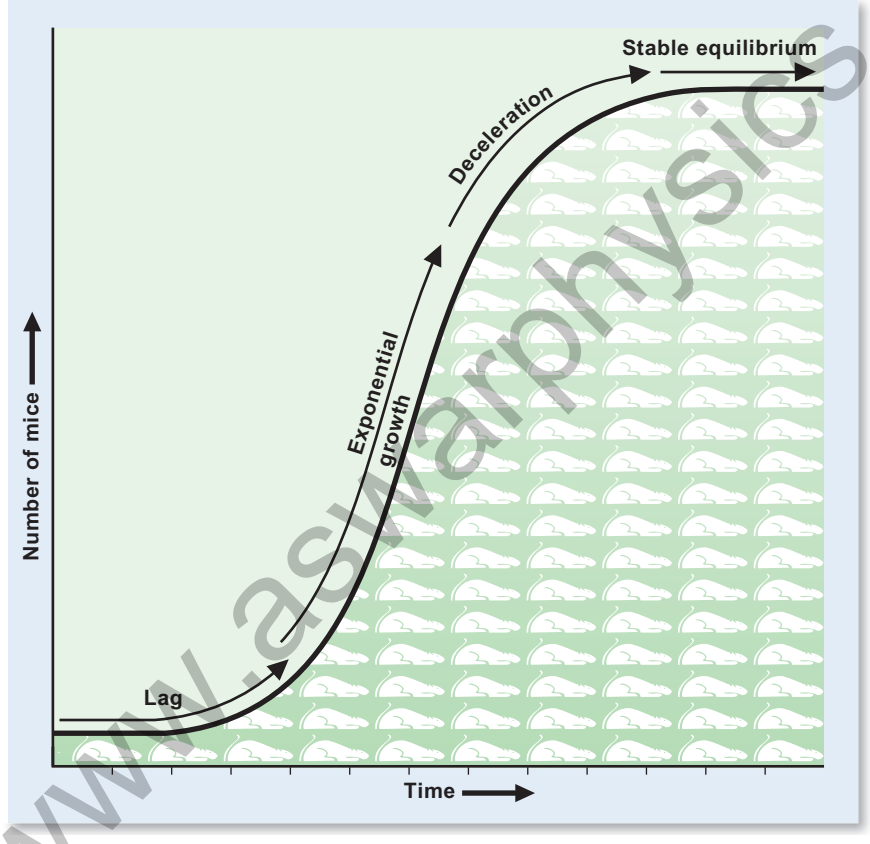


FIGURE 17.8 A Typical Population Growth Curve
In this mouse population, the period of time in which there is little growth is known as the lag phase. This is followed by a rapid increase in population as the offspring of the originating population begin to reproduce themselves; this is known as the exponential growth phase. Eventually, the population growth rate begins to slow during the deceleration phase and the population reaches a stable equilibrium phase, during which the birthrate equals the death rate.

The Lag Phase

The **lag phase** of a population growth curve is the period of time immediately following the establishment of a population, when the population remains small and fairly constant. During the lag phase, both natality and mortality are low.

The lag phase occurs because reproduction is not an instantaneous event. Even after animals enter an area, they must mate and produce young. This may take days or years, depending on the animal. Similarly, new plant introductions must grow to maturity, produce flowers, and set seed. Some annual plants do this in less than a year, whereas some large trees take several years of growth before they produce flowers. In organisms that take a long time to mature and produce young, such as elephants, deer, and many kinds of plants, the lag phase may be measured in years.

The Exponential Growth Phase

The **exponential growth phase** of a population growth curve is the period of time when a population is growing rapidly. Exponential growth results in a population increasing by the same percent each year. For example, if the population were to double each year we would have 2, 4, 8, 16, 32, etc. individuals in the population. A population of mice is a good example of why populations can increase rapidly. Assuming that the population is started by a single pair—a male and female—it will take some time for them to mate and produce their first litter of offspring. This is the lag phase. However, once the first litter of young has been produced, the population is likely to increase rapidly. The first litter of young will become sexually mature and able to reproduce in a matter of weeks. If the usual litter size for a pair of mice is 4, the 4 produce 8, which in turn produce 16, and so forth. Furthermore, the original parents will probably produce an additional litter or two during this time period. Now, several pairs of mice are reproducing more than just once. With several pairs of mice reproducing, natality increases while mortality remains low; therefore, the population begins to grow at an ever-increasing rate. However, the population cannot continue to increase indefinitely. Eventually, the rate at which the population is growing will begin to level off.

The Deceleration Phase

A **deceleration phase** eventually occurs during which the population growth rate begins to slow. The number entering the population by

reproduction remains high but the number leaving by death increases and the population growth rate begins to slow. The size of the population continues to grow but at a slower and slower rate until natality and mortality become equal. At this point, the population will enter the stable equilibrium phase.

The Stable Equilibrium Phase

The **stable equilibrium phase** of a population growth curve is the period of time when a population stops growing and maintains itself at a reasonably stable level. This occurs because the number of individuals entering the population by birth will come to equal the number of individuals leaving it by death or migration. The number of organisms cannot continue to increase indefinitely, because eventually something in the environment will become limiting and cause an increase in the number of deaths. For animals, food, water, or nesting sites may be in short supply, or predators or disease may kill many individuals. Plants may lack water, soil nutrients, or sunlight. Often, there is both a decrease in natality and an increase in mortality as a population reaches the stable equilibrium phase. Although the size of the population is stable, the individuals in the population are changing. Birth, death, and migration are still going on, resulting in a changing mix of individuals. The size of the population is stable because there is an equilibrium between those entering and those leaving the population.

Alternate Population Growth Strategies

When ecologists look at many kinds of organisms and how their populations change, they recognize two general types of reproductive strategies. These are often referred to as K-strategists and r-strategists. The *K* and *r* notations come from a mathematical formula where the *K* represents the carrying capacity and the *r* represents the population growth rate.

1. K-strategists are large organisms that live a long time and tend to reach a population size that can be sustained over an extended period. These kinds of organisms follow the pattern of population growth just described.
2. r-strategists are organisms that are small and have short life spans, tend to have fluctuating populations, and do not reach a stable equilibrium phase during population growth. Their populations go through the normal pattern of beginning with a lag phase, followed by an exponential growth phase. However, they typically reach a maximum, followed by a rapid decrease in population often called a "crash" (figure 17.9).

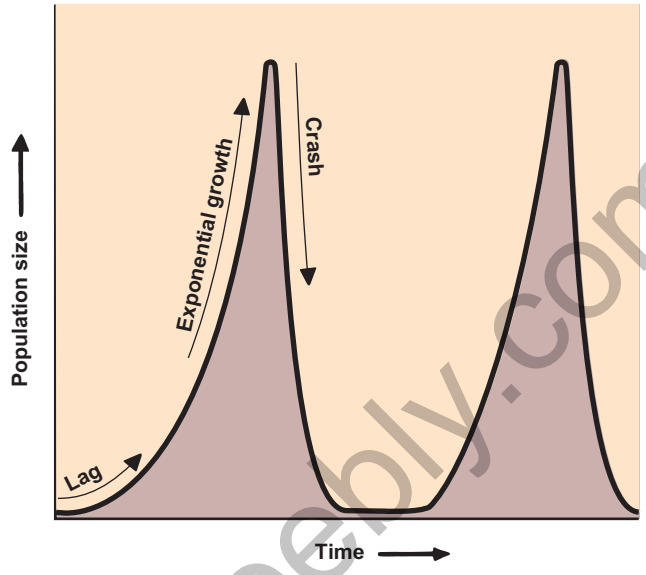


FIGURE 17.9 A Population Growth Curve for Short-Lived Organisms
Organisms that are small and live only a short time often show this kind of population growth curve. There is a lag phase, followed by an exponential growth phase. However, instead of entering into a stable equilibrium phase, the population reaches a maximum and crashes.

17.3 CONCEPT REVIEW

7. Draw a population growth curve. Label the lag, exponential growth, deceleration, and stable equilibrium phases.
8. What causes a lag phase in a population growth curve? An exponential growth phase? A deceleration phase? A stable equilibrium phase?
9. Describe how the population growth curves of K-strategists and r-strategists differ.

17.4 Limits to Population Size

Populations cannot continue to increase indefinitely. Eventually, a factor or combination of factors limits their size. The factors that prevent unlimited population growth are known as **limiting factors.** All the limiting factors that act on a population are collectively known as **environmental resistance.**

Extrinsic and Intrinsic Limiting Factors

Some factors that control populations come from outside the population and are known as **extrinsic limiting factors.** Predators, the loss of a food source, a lack of sunlight, and accidents of nature are all extrinsic factors. However, the populations of many kinds of organisms appear to be regulated by

factors from within the populations themselves. Such limiting factors are called **intrinsic limiting factors.** For example, a study of rats under crowded living conditions showed that, as conditions became more crowded, abnormal social behavior became common. There was a decrease in litter size, fewer litters per year were produced, the mothers were more likely to ignore their young, and many young were killed by adults. Thus, changes in the rats' behavior resulted in lower birth-rates and higher death rates, which limit population size. In another example, the reproductive success of white-tailed deer is reduced when the deer experience a series of severe winters. When times are bad, the female deer are more likely to have single offspring than twins.

Density-Dependent and Density-Independent Limiting Factors

Density-dependent limiting factors are those that become more effective as the density of the population increases. For example, the larger a population becomes, the more likely that predators will have a chance to catch some of the individuals. A prolonged period of increasing population allows the size of the predator population to increase as well. Disease epidemics are also more common in large, dense populations, because dense populations allow for the easy spread of parasites from one individual to another. The rat example previously mentioned also illustrates a density-dependent limiting factor in operation—the amount of abnormal behavior increased as the density of the population increased. In general, whenever there is competition among the members of a population, the intensity of competition increases as the population density increases. Large organisms that tend to live a long time and have relatively few young (K-strategists) are most likely to be controlled by density-dependent limiting factors.

Density-independent limiting factors are population-controlling influences that are not related to the density of the population. They are usually accidental or occasional extrinsic factors in nature that happen regardless of the density of a population. A sudden rainstorm may drown many small plant seedlings and soil organisms. Many plants and animals are killed by frosts in late spring or early fall. A small pond may dry up, resulting in the death of many organisms. The organisms most likely to be controlled by density-independent limiting factors are small, short-lived organisms that can reproduce very rapidly (r-strategists).

17.4 CONCEPT REVIEW

10. Differentiate between density-dependent and density-independent limiting factors. Give an example of each.
11. Differentiate between intrinsic and extrinsic limiting factors. Give an example of each.

17.5 Categories of Limiting Factors

Limiting factors can be placed in four broad categories:

1. Availability of raw materials
2. Availability of energy
3. Production and disposal of waste products
4. Interaction with other organisms

Availability of Raw Materials

The availability of raw materials is an extremely important limiting factor. For example, plants require magnesium to manufacture chlorophyll, nitrogen to produce protein and water to transport materials and as a raw material for photosynthesis. If these substances are not present in the soil, the growth and reproduction of plants are inhibited. However, if fertilizer supplies these nutrients, or if irrigation supplies water, the effects of these limiting factors can be removed, and a different factor becomes limiting. For animals, the amount of water, minerals, materials for nesting, suitable burrow sites, and food may be limiting factors.

Availability of Energy

The availability of energy is a major limiting factor, because all living things need a source of energy. The amount of light available is often a limiting factor for plants, which require light as an energy source for photosynthesis. Because all animals use other living things as sources of energy and raw materials, a major limiting factor for any animal is its food source.

Accumulation of Waste Products

The accumulation of waste products can significantly limit the size of populations. It does not usually limit plant populations, however, because they produce relatively few wastes. However, the buildup of high levels of self-generated waste products is a problem for bacterial populations and populations of tiny aquatic organisms. As wastes build up, they become more and more toxic, and eventually reproduction stops, or the population dies out. For example, when a few bacteria are introduced into a solution containing a source of food, they go through the kind of population growth curve typical of all organisms. As expected, the number of bacteria begins to increase following a lag phase, increases rapidly during the exponential growth phase, enters a deceleration phase, and eventually reaches stability in the stable equilibrium phase. However, as waste products accumulate, the bacteria drown in their own wastes. When space for disposal is limited, and no other organisms are present that can convert the harmful wastes to less harmful products, a population decline, known as the **death phase,** follows (figure 17.10).

In small pools, such as aquariums, it is often difficult to keep organisms healthy because of the buildup of ammonia in the water from the animals' waste products. This is the

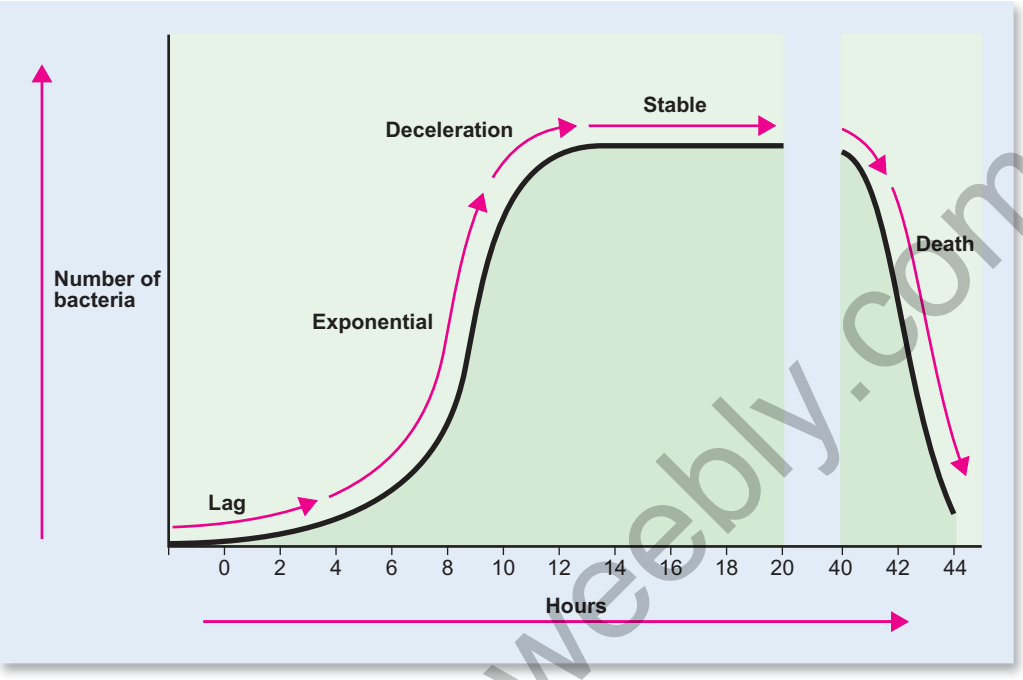


FIGURE 17.10 Bacterial Population Growth Curve
The rate of increase in the size of the population of these bacteria is typical of population growth in a favorable environment. When the environmental conditions worsen as a result of an increase in the amount of waste products, the population first levels off, then begins to decrease. This period of decreasing population size is known as the death phase or decline phase.

primary reason that activated charcoal filters are used in aquariums. The charcoal removes many kinds of toxic compounds and prevents the buildup of waste products.

Interaction with Other Organisms

Organism interactions are also important in limiting population size. Recall from chapter 16 that organisms influence each other in many ways. Some interactions are harmful; others are beneficial.

Predation, parasitism, and competition tend to limit the growth of populations and their maximum size. Parasitism and predation usually involve interactions between two different species. Thus, they are extrinsic limiting factors. Competition between members of different species (interspecific competition) is an extrinsic limiting factor. Competition among members of the same species (intraspecific competition) is an intrinsic limiting factor and often is extremely intense.

On the other hand, many kinds of organisms perform beneficial services for others that allow the population to grow more than it would without the help. For example, decomposer organisms destroy toxic waste products, thus benefiting populations of aquatic animals. They also recycle the materials that all organisms need for growth and development. Mutualistic relationships benefit both populations involved. The absence of such beneficial organisms is a limiting factor.

Often, the population sizes of two kinds of organisms are interdependent, because each is a primary limiting factor of the other. This is most often seen in parasite-host relationships and predator-prey relationships.

A study of the population biology of the collared lemming (*Dicrostonyx groenlandicus*) in Greenland illustrates the population interactions between lemmings and four predators. Lemmings have a very high reproductive capacity, producing two or three litters per year. However, their population is held in check by four predators. Three—the snowy owl, the arctic fox, and the long-tailed skua (a bird that resembles a gull)—are generalist predators, whose consumption of lemmings is directly related to the size of the lemming population. They constitute a density-dependent limiting factor for the lemming population. When lemming numbers are low, these predators seek other prey.

The fourth lemming predator is the short-tailed weasel (*Mustela ermina*); it is a specialist predator on lemmings. The weasels are much more dependent on lemmings for food than are the other three predators. The weasels mate once a year, so their population increases at a slower rate than that of the lemmings. However, as the weasel population increases, it eventually become large enough that it drives down the lemming population. The resulting decrease in lemmings leads to a decline in the number of weasels, which allows for the greater survival of lemmings, which ultimately leads to another cycle of increased weasel numbers (figure 17.11). Outlooks 17.1 provides an example of how interactions between humans and leatherback turtles have negatively affected turtle populations.

17.5 CONCEPT REVIEW

12. List four kinds of limiting factors that help set the carrying capacity for a species.
13. Describe an example of how waste products can limit the size of a population.
14. Give an example of how interaction between two species of organisms could allow for populations to be larger than if the interaction did not occur.

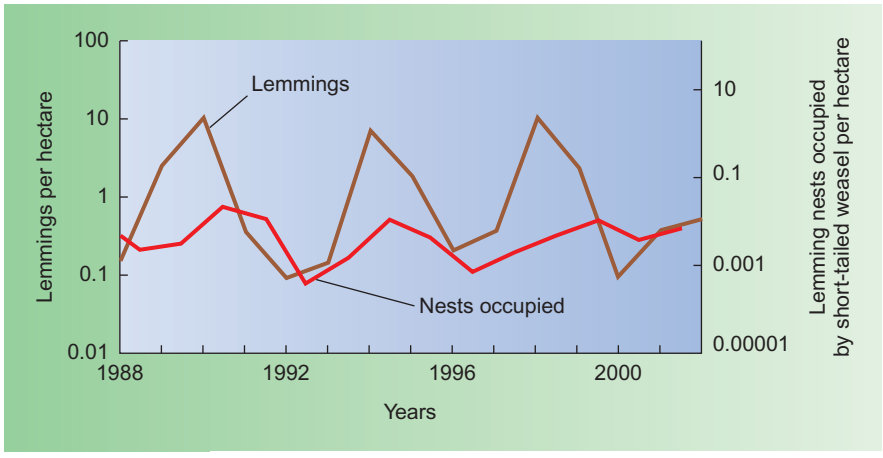


FIGURE 17.11 Population Cycles
In many northern regions of the world, population cycles are common. In the case of collared lemmings and short-tailed weasels in Greenland, interactions between the two populations result in population cycles of about 4 years. The graph shows the population of lemmings per hectare and the number of lemming nests occupied by weasels per hectare. The researchers used the number of nests occupied by weasels as an indirect measure of weasel population size.

OUTLOOKS 17.1

Marine Turtle Population Declines

Throughout the world, all seven species of marine turtles are endangered. There are several characteristics of their life history and reproductive biology that contribute to this problem. Although there are some differences among the species, in general they are slow to mature and there is high mortality among the young.

Some details about the leatherback turtle *(Dermochelys coriacea)* will help to describe why marine turtles are in trouble. Leatherback turtles are the largest of the marine turtles that are in the range of 1–2 meters in length and between 250 and 700 kg in weight. They reach sexual maturity between 6 and 10 years of age. Once a female turtle reaches sexual maturity she will nearly always return to the beach from which she hatched to lay her eggs. She generally arrives at the beach at night at high tide and drags herself up the sandy beach where she digs a hole in the sand with her rear flippers and deposits up to 100 eggs. She then covers the eggs with sand and leaves. She may lay eggs several times during the breeding season, but it may be two to three years before she returns to lay more eggs.

The eggs hatch after about 60 days. At night the hatchlings crawl up through the sand and migrate down the beach to the ocean. If they are successful in reaching the water they still need to live to maturity. Although large adult turtles have few predators, the hatchlings and small turtles are prey to many birds, mammals, crabs, and fish. In addition, terrestrial mammals may find and eat the eggs. Survival is low. Some researchers estimate that about 1 hatchling per 1,000 makes it to adulthood.

Several kinds of human activities reduce survival. Although marine turtles are a protected species worldwide, in many parts of the world people dig up the eggs of the turtles or capture turtles for food. In addition, the building of resorts and other urban development alters the beaches traditionally used by the turtles. Even the lights associated with urban development are a problem. In particular, the hatchlings rely on light stimuli to guide them to the water. In the absence of human lights, the surface of the water reflects light, which the hatchlings follow to the water. If there are other sources of light, the hatchlings may orient on lights that lead them away from the water. Human fishing activity also results in the death of many young and adult turtles. If turtles become entangled in nets or are caught on a submerged fishing hook, they will be unable to surface to breathe and will drown. Even discarded plastic in the ocean is a problem—plastic bags resemble jellyfish that are the primary food of the turtles. The turtles eat, but cannot digest them, and the bags block their digestive system, causing death.

So, a combination of factors contributes to the endangered status of the leatherback turtle:

1. Sandy beaches are required as a suitable nesting habitat and they need to be isolated or protected from human predation on the eggs and adults.
2. Mortality of the hatchlings and young is very high due to a combination of natural predation and accidental capture by fishers.
3. Many turtle nesting beaches are also desirable as recreation sites. New resort facilities and the lights associated with them lead to inadvertent deaths of the hatchling turtles.

Female leatherback turtle fitted with a tracking device

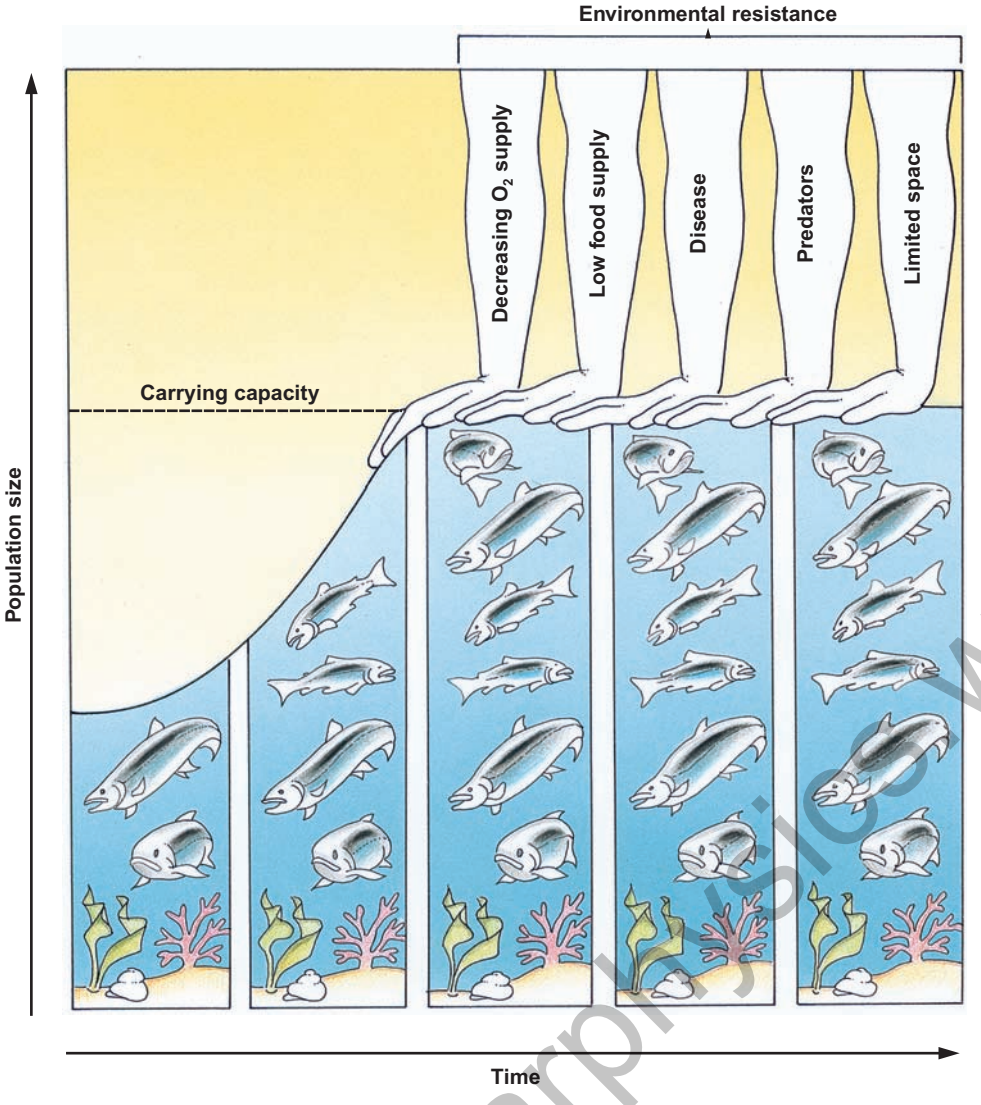


FIGURE 17.12 Carrying Capacity
A number of factors in the environment, such as food, oxygen supply, diseases, predators, and space, determine the maximum number of organisms that can be sustained in a given area—the carrying capacity of that area. The environmental factors that limit populations are collectively known as environmental resistance.

17.6 Carrying Capacity

Many populations reach a maximum size when they reach the stable equilibrium phase. This suggests that the environment sets an upper limit on population size. The **carrying capacity** is the maximum sustainable population for an area. The carrying capacity is determined by a combination of limiting factors. But keep in mind that some limiting factors are more important than others (figure 17.12).

Carrying capacity is not an inflexible number, however. Often, such environmental differences as successional changes, climatic variations, disease epidemics, forest fires, and floods can change the carrying capacity of an area for specific species. In aquatic ecosystems, one of the major factors that determine the carrying capacity is the quantity of nutrients in the water. Where nutrients are abundant, the numbers of various kinds of organisms are high. Often, nutrient levels fluctuate with changes in current or runoff from the land, and plant and animal populations fluctuate as well. In addition, a change that negatively affects the carrying capacity for one species may increase the carrying capacity for another. For example, the cutting down of a mature forest followed by the growth of young trees increases the carrying capacity for deer and rabbits, which use the new growth for food, but decreases the carrying capacity for squirrels, which need mature, fruit-producing trees as a source of food and old, hollow trees for shelter.

Wildlife management practices often encourage modifications to the environment that will increase the carrying capacity for the designated game species. The goal of wildlife managers is to have the highest sustainable population available for harvest by hunters. Typical habitat modifications include creating water holes, cutting forests to provide young growth, planting food plots, and building artificial nesting sites.

In some cases, the size of the organisms in a population also affects the carrying capacity. For example, an aquarium of a certain size can support only a limited number of fish, but the size of the fish makes a difference. If all the fish are tiny, a large number can be supported, and the carrying capacity is high; however, the same aquarium may be able to support only one, large fish. In other words, the biomass of the population makes a difference (figure 17.13). Similarly, when an area is planted with small trees, the population size is high; however, as the trees get larger, competition for nutrients and sunlight becomes more intense, and the number of trees declines as the biomass increases.

17.6 CONCEPT REVIEW

15. How is the carrying capacity of an environment related to the stable equilibrium phase of a population growth curve?
16. How are the concepts of carrying capacity and limiting factors related?
17. Describe an event that could change the carrying capacity for an organism and explain why the event would alter carrying capacity.

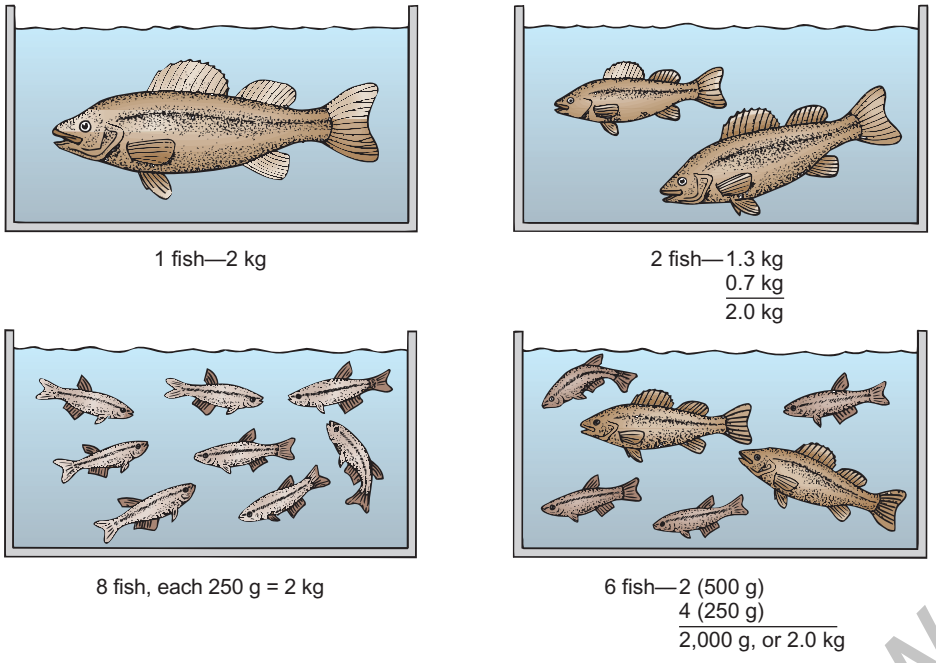


FIGURE 17.13 The Effect of Biomass on Carrying Capacity
Each aquarium can support a biomass of 2 kilograms of fish. The size of the population is influenced by the body size of the fish in the population.

17.7 Limiting Factors to Human Population Growth

Today we hear differing opinions about the state of the world's human population. On one hand we hear that the population is growing rapidly. By contrast we hear that some countries are afraid that their populations are shrinking. Other countries are concerned about the aging of their populations, because birthrates and death rates are low. In magazines and on television, we see that there are starving people in the world. At the same time, we hear discussions about the problem of food surpluses and obesity in many countries. Some have even said that the most important problem in the world today is the rate at which the human population is growing. Others maintain that the growing population will provide markets for goods and be an economic boon. How do we reconcile this mass of conflicting information?

It is important to realize that human populations follow the same patterns of growth and are acted on by the same kinds of limiting factors as are populations of other organisms. The growth of the human population over the past several thousand years follows a pattern that resembles the lag and exponential growth phases of a population growth curve. It is estimated that the human population remained low and constant for thousands of years but has increased rapidly in the past few hundred years (figure 17.14). For example, it has been estimated that before European discovery, the Native American population was at or near its carrying capacity. Although it is impossible to know the Native American population at that time, various experts estimate it was between 1 million and 18 million. Today, the population of the United States is nearly 310 million people. Does this mean that humans are different from other animal species? Can the human population continue to grow forever?

The human species has an upper limit set by the carrying capacity of the environment, as does any other species. However, the human population has been able to increase astronomically because technological changes and the displacement of other species have allowed us to shift the carrying capacity upward. Much of the exponential growth phase of the human population can be attributed to improved sanitation, the control of infectious diseases, improvements in agricultural methods, and the replacement of natural ecosystems with artificial agricultural ecosystems. But even these conditions have their limits. Some limiting factors will eventually cause a leveling off of our population growth curve. We cannot increase beyond our ability to get raw materials and energy, nor can we ignore the waste products we produce and the other organisms with which we interact.

Availability of Raw Materials

To many of us, raw materials consist simply of the amount of food available, but we should not forget that, in a technological society, iron ore, lumber, irrigation water, and silicon chips are also raw materials. However, most people of the world have much more basic needs. For the past several decades, large portions of the world's population have not had enough food (figure 17.15). Although it is biologically accurate to say that the world can currently produce enough food for everyone, there are complex political, economic, and social issues related to food production and distribution. Probably most important is the fact that the transportation of food from centers of excess to centers of need is often very difficult and expensive. Societies with excess food have been unwilling to bridge these political and economic gaps.

However, a more fundamental question is whether the world can continue to produce enough food. In 2010, the world population was growing at a rate of 1.2% per year. This amounts to about 150 new people added to the population every minute. This would result in an increase from our current population of nearly 6.9 billion to about 9.5 billion by 2050. With a continuing increase in the number

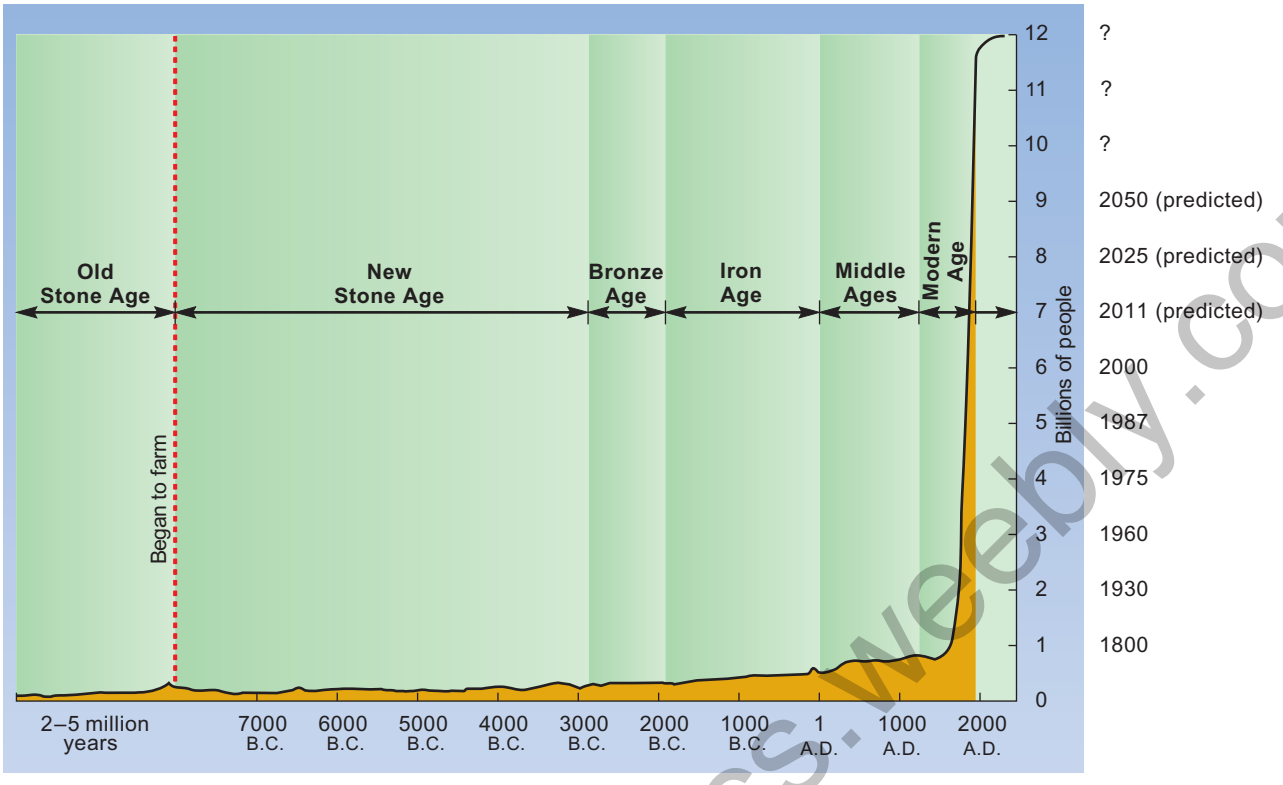


FIGURE 17.14 Human Population Growth
The number of humans doubled from A.D. 1800 to 1930 (from 1 billion to 2 billion), had doubled again by 1975 (4 billion), and is projected to double again (8 billion) by about 2025. How long can the human population continue to double before the Earth's ultimate carrying capacity is reached?

FIGURE 17.15 Food Is a Raw Material

of mouths to feed, it is unlikely that food production will be able to keep pace with the growth in human population (How Science Works 17.1).

A primary indicator of the status of the world food situation is the amount of grain produced for each person in the world (per capita grain production). World per capita grain production peaked in 1984.

Availability of Energy

The availability of energy also affects human populations. All species on Earth ultimately depend on sunlight for energy. All energy—whether power from a hydroelectric dam, fossil fuels, or solar cell—is derived from the Sun. Energy is needed for transportation, the construction and maintenance of homes, and food production. It is very difficult to develop unbiased, reasonably accurate estimates of global energy reserves in the form of petroleum, natural gas, and coal. Therefore, it is difficult to predict how long these reserves might last. However, the quantities are limited and the rate of use has been increasing (figure 17.16).

If the less-developed countries were to attain a standard of living equal to that of the developed nations, the global

HOW SCIENCE WORKS 17.1

Thomas Malthus and His Essay on Population

In 1798, Thomas Robert Malthus, an Englishman, published an essay on human population, presenting an idea that was contrary to popular opinion. His basic thesis was that the human population increased in a geometric, or exponential, manner (2, 4, 8, 16, 32, 64, etc.), whereas the ability to produce food increased only in an arithmetic manner (1, 2, 3, 4, 5, 6, etc.). The ultimate outcome of these different rates would be that the population would outgrow the land's ability to produce food. He concluded that wars, famines, plagues, and natural disasters would be the means (limiting factors) of controlling the size of the human population. His predictions were hotly debated by the intellectual community of his day, and his assumptions and conclusions were attacked as erroneous and against the best interest of society. At the time he wrote the essay, the popular opinion was that human knowledge and "moral constraint" would be able to create a world that would supply all human needs in abundance. One of Malthus's basic postulates was that "commerce between the sexes" (sexual intercourse) would continue unchanged. Other philosophers of the day believed that sexual behavior would take less procreative forms and the human population would be limited. Only within the past 50 years, however, have effective conception-control mechanisms become widely accepted and used. However, even today they are used primarily in the more developed countries of the world.

Thomas Robert Malthus

Malthus did not foresee the use of contraception, major changes in agricultural production techniques, or the exporting of excess people to colonies in the Americas. These factors, as well as high death rates, prevented the most devastating of his predictions from coming true. However, in many parts of the world, people are experiencing the forms of population control (famine, epidemic disease, wars, and natural disasters) that Malthus predicated in 1798. Many people believe that his original predictions were valid—only his time scale was not correct—and that his predictions are coming true today.

Another important impact of Malthus's essay was its effect on young Charles Darwin. When Darwin read it, he saw that what was true for the human population could be applied to the whole of the plant and animal kingdoms. As over-reproduction took place, there would be increased competition for food, resulting in the death of the less-fit organisms. This was an important part of his theory of natural selection.

FIGURE 17.16 Humans' Energy Use

energy reserves would disappear overnight. People should realize that there is a limit to our energy resources; we are living on solar energy that was stored over millions of years, and we are using it at a rate that could deplete it in hundreds of years.

Accumulation of Wastes

One of the most talked about aspects of human activity is the problem of waste disposal. We have normal biological wastes, which can be dealt with by decomposer organisms. However, we also generate a variety of technological wastes and by-products that cannot be degraded efficiently by decomposers (figure 17.17). Most of what we call pollution results from the waste products of technology. The biological wastes usually can be dealt with fairly efficiently by building wastewater treatment plants and other sewage facilities. Certainly, these facilities take energy to run, but they rely on decomposers to degrade unwanted organic matter to carbon dioxide and water. Earlier in this chapter, we discussed the problems

FIGURE 17.17 Human Waste Production

FIGURE 17.18 Interaction with Other Organisms

aquarium organisms face when their metabolic waste products accumulate. In this situation, the organisms so "befoul their nest" that their wastes poison them. Are humans in a similar situation on a much larger scale? Are we dumping so much technological waste, much of it toxic, into the environment that we are being poisoned? Is carbon dioxide from the burning of fossil fuels changing our climate?

Interactions with Other Organisms

Humans interact with other organisms in as many ways as other animals do. We have parasites and, occasionally, predators. We are predators in relation to a variety of animals, both domesticated and wild. We have mutualistic relationships with many of our domesticated plants and animals, because they could not survive without our agricultural practices, and we would not survive without the food they provide. Competition is also very important. Insects and rodents compete for the food we raise, and we compete directly with many other kinds of animals for the use of ecosystems.

As humans convert more and more land to agriculture and other purposes, many other organisms are displaced (figure 17.18). Many of these displaced organisms are not able to compete successfully and must leave the area, reduce their populations, or become extinct. The American bison (buffalo), African and Asian elephants, panda, and grizzly bear are a few species that have reduced populations because they were not able to compete successfully with the human species. The passenger pigeon, Carolina parakeet, and great auk are a few that have become extinct. Our parks and natural areas have become tiny refuges for plants and animals that once occupied vast expanses of the world. If these refuges are lost, many organisms will become extinct. What today might seem to be an insignificant organism may tomorrow be seen as a link to our very survival. We humans have been extremely successful in our efforts to convert ecosystems to our own uses at the expense of other species.

Competition with one another (intraspecific competition), however, is a different matter. Because competition is negative for both organisms, competition between humans harms humans. We are not displacing another species; we are displacing our own kind. Certainly, when resources are in short supply, there is competition. Unfortunately, it is usually the young who are least able to compete, and high infant mortality is the result.

17.7 CONCEPT REVIEW

18. As the human population continues to grow, what should we expect to happen to other species?
19. How does the shape of the population growth curve of humans compare with that of other kinds of animals?

17.8 The Control of the Human Population—A Social Problem

Humans are different from most other organisms in a fundamental way: We are able to predict the outcome of a specific course of action. Current technology and medical knowledge are available to control the human population and improve the health and well-being of the people of the world. Why, then, does the human population continue to grow, resulting in human suffering and stressing the environment in which we live? Because we are social animals with freedom of choice, we frequently do not do what is considered best from an unemotional, unselfish, biological point of view. People make decisions based on historical, social, cultural, ethical, and personal considerations. In order to control the human population, individuals may need to set aside some of their wants and desires.