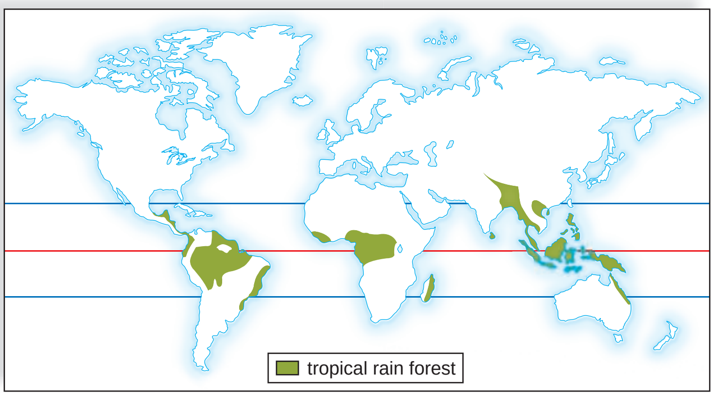
dry seasons are found in India, Southeast Asia, West Africa, South and Central America, the West Indies, and northern Australia. Here, there are deciduous trees, with many layers of growth beneath them.

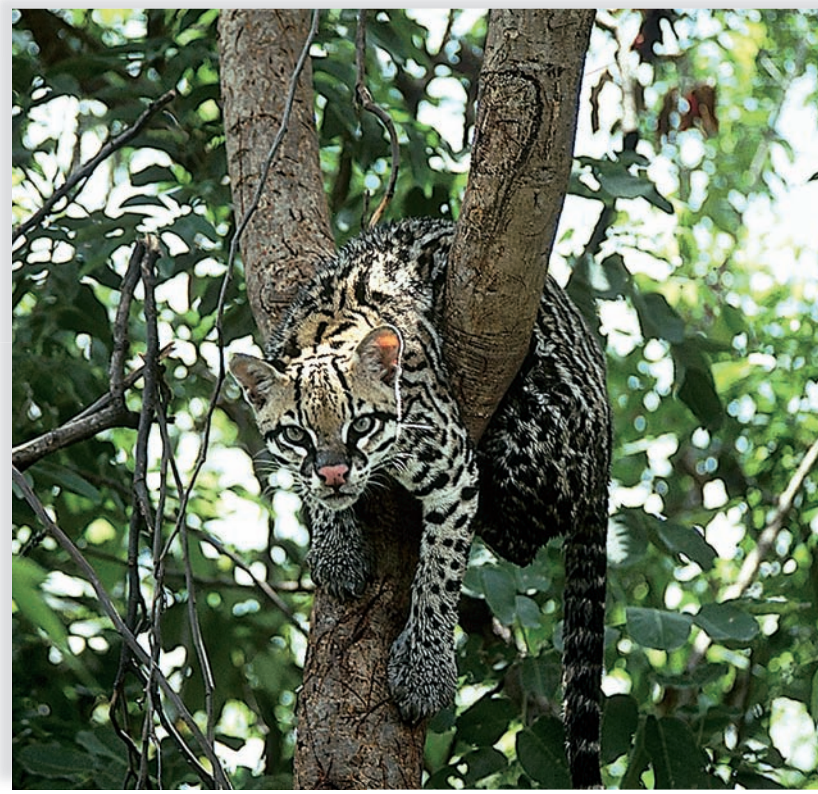
Whereas the soil of a temperate deciduous forest biome is rich enough for agricultural purposes, the soil of a tropical rain forest biome is not. Nutrients are cycled directly from the litter to the plants again. Productivity is high because of high temperatures, a yearlong growing season, and the rapid recycling of nutrients from the litter. (In humid tropical forests, iron and aluminum oxides occur at the surface, causing a reddish residue known as laterite. When the trees are cleared, laterite bakes in the hot sun to a bricklike consistency that will not support crops.) Swidden agriculture, often called slash-and-burn agriculture, has been successful, but also destructive, in the tropics. Trees are felled and burned, and the ashes provide enough nutrients for several harvests. Thereafter, the forest must be allowed to regrow, and a new section must be cut and burned.

It is estimated that 2.4 acres of rain forest are destroyed per second. This rate equates to nearly 78 million acres annually. Unless conservation strategies are employed soon, rain forests will be destroyed beyond recovery, taking with them unique and interesting life-forms. Ecologists estimate that an average of 137 species are driven to extinction every day in rain forests.



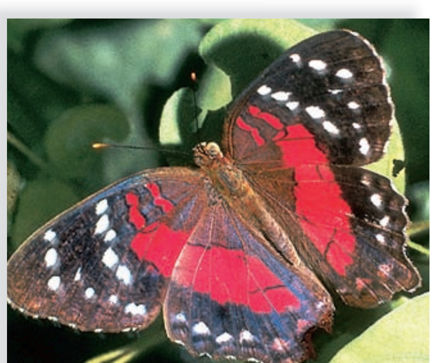
Poison arrow frog,
Dendrobates azureus

Cone-headed katydid,
Panacanthus cuspidatus



Ocelot,
Felis pardalis

Blue and gold macaw,
Ara ararauna



Brush-footed butterfly,
Anartia amalthea linnaeus

Lemur,
Propithecus verreauxi

Arboreal lizard,
Calotes calotes

FIGURE 46.10 **Location (green) and representative animals of the tropical rain forests of the world.**

Shrublands

It is difficult to define a shrub, but in general, shrubs are shorter than trees (4.5–6 m) with a woody, persistent stem and no central trunk. Shrubs have small but thick evergreen leaves, which are often coated with a waxy material that prevents loss of moisture from the leaves. Their thick underground roots can survive dry summers and frequent fires and take deep moisture from the soil. Shrubs are adapted to withstand arid conditions and can also quickly sprout new growth after a fire. As a point of interest, you will recall from Chapter 45 that a shrub stage is part of the process of both primary and secondary succession.

Shrublands tend to occur along coasts that have dry summers and receive most of their rainfall in the winter. Shrublands are found along the cape of South Africa, the western coast of North America, and the southwestern and southern shores of Australia, as well as around the Mediterranean Sea and in central Chile. The dense shrubland that occurs in California is known as **chaparral** (Fig. 46.11). This type of shrubland, called Mediterranean, lacks an understory and ground litter and is highly flammable. The seeds of many species require the heat and scarring action of fire to induce germination. Other shrubs sprout from the roots after a fire. Typical animals of the chaparral include mule deer, rodents, lizards, and scrub jays.

There is also a northern shrub area that lies west of the Rocky Mountains. This area is sometimes classified as a cold desert, but the region is dominated by sagebrush. Some of the birds found there are dependent on sagebrush for their existence.

Grasslands

Grasslands occur where annual rainfall is greater than 25 cm but generally insufficient to support trees. For example, in temperate areas, where rainfall is between 25 and 75 cm, it is too dry for forests and too wet for deserts to form.

Grasses are well adapted to a changing environment and can tolerate a high degree of grazing, flooding, drought, and sometimes fire. Where rainfall is high, tall grasses that reach more than 2 m in height (e.g., pampas grass) can flourish. In drier areas, shorter grasses (between 5 and 10 cm) are dominant. Low-growing bunch grasses (e.g., grama grass) grow in the United States near deserts. The growth of grasses is seasonal. As a result, grassland animals such as bison migrate, and others such as ground squirrels hibernate, when there is little grass for them to eat.

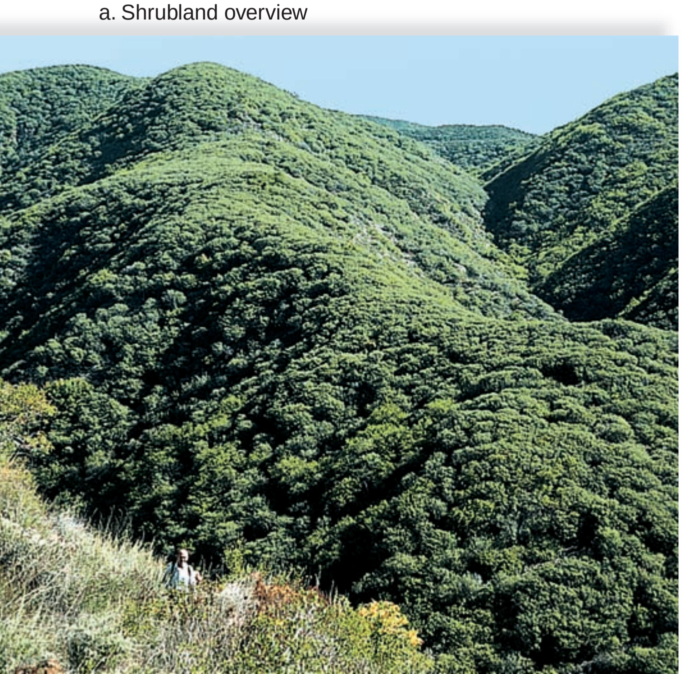
Temperate Grasslands

The temperate grasslands include the Russian steppes, the South American pampas, and the North American prairies (Fig. 46.12). In these grasslands, winters are bitterly cold and summers are hot and dry. When traveling across the United States from east to west, the line between the temperate deciduous forest and a tall-grass prairie is roughly along the border between Illinois and Indiana. The tall-grass prairie receives more rainfall than does the short-grass prairie, which occurs near deserts. Large herds of bison—estimated at hundreds of thousands—once roamed the prairies, as did herds of pronghorn antelope. Now, small mammals, such as mice, prairie dogs, and rabbits, typically live belowground, but usually feed aboveground. Hawks, snakes, badgers, coyotes, and foxes feed on these mammals. Virtually all of these grasslands, however, have been converted to agricultural lands because of their fertile soils.

Savannas

Savannas occur in regions where a relatively cool dry season is followed by a hot rainy season (Fig. 46.13). The largest savannas are in central and southern Africa. Other savannas exist in Australia, southeast Asia, and South America. The savanna is characterized by large expanses of grasses with sparse populations of trees. The plants of the savanna have extensive and deep root systems that enable them to survive drought and fire. One tree that can survive the severe dry season is the thorny flat-topped *Acacia,* which sheds its leaves during a drought. The African savanna supports

a. Shrubland overview



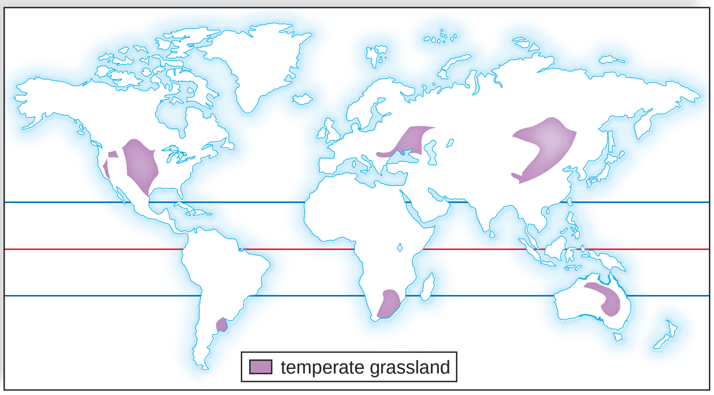
b. Scrub jay, *Aphelocoma californica*

c. Chemise, *Adenostema faciculatum*

FIGURE 46.11 Shrubland.

a. Shrublands, such as chaparral in California, are subject to raging fires, but the shrubs are adapted to quickly regrow. **b.** Scrub jays find a home here as does (**c**) a plant commonly called chemise.

the greatest variety and number of large herbivores of all the biomes. Elephants and giraffes are browsers that feed on tree vegetation. Antelopes, zebras, wildebeests, water buffalo, and rhinoceroses are grazers that feed on grasses. Any plant litter that is not consumed by grazers is attacked by a variety of small organisms, among them termites. Termites build towering nests in which they tend fungal gardens, their source of food. The herbivores support a large population of carnivores. Lions and hyenas sometimes hunt in packs, cheetahs hunt singly by day, and leopards hunt singly by night.

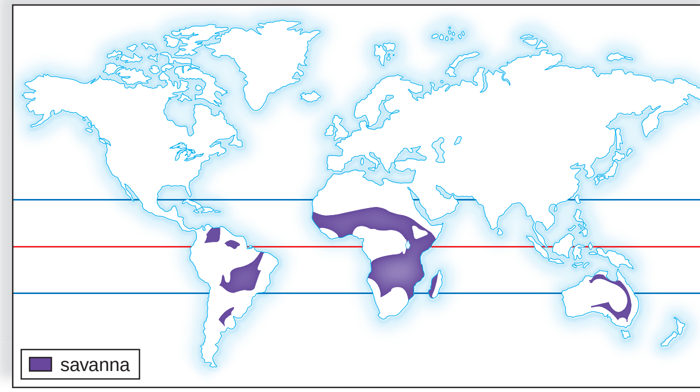


a. Temperate grassland vegetation and location (purple)

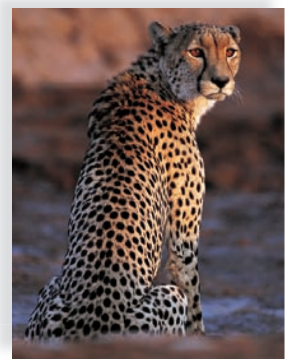
b. American bison, *Bison bison*, a large mammal

FIGURE 46.12 Temperate grassland.

a. Tall-grass prairies are seas of grasses dotted by pines and junipers. **b.** Bison, once abundant, are now being reintroduced into certain areas.



a. Location of savanna biome



Cheetah, *Acinonyx jubatus*

Giraffe, *Giraffa camelopardalis*

Wildebeest, *Connochaetes* sp.

Zebra (in foreground), *Equus quagga*
b. Animal life of savanna biome

FIGURE 46.13 The savanna.

a. The African savanna, located as shown, varies from grassland to widely spaced shrubs and trees. **b.** This biome supports a large assemblage of herbivores (e.g., zebras, wildebeests, and giraffes). Carnivores (e.g., cheetahs) prey on these.

Deserts

Deserts are usually found at latitudes of about 30°, in both the Northern and Southern Hemispheres. Deserts cover nearly 30% of the Earth's land surface. The winds that descend in these regions lack moisture. Therefore, the annual rainfall is less than 25 cm. Days are hot because a lack of cloud cover allows the sun's rays to penetrate easily, but nights are cold because heat escapes easily into the atmosphere.

The Sahara, which stretches all the way from the Atlantic coast of Africa to the Arabian peninsula, and a few other deserts have little or no vegetation. However, most deserts have a variety of plants (Fig. 46.14*a*) that are highly adapted to survive long droughts, extreme heat, and extreme cold. Adaptations to these conditions include thick epidermal layers, water-storing succulent stems and leaves, and the ability to set seeds quickly in the spring. The best-known desert perennials in North America are the spiny cacti, which have stems that store water and carry on photosynthesis. Also common are nonsucculent shrubs, such as the many-branched sagebrush with silvery gray leaves and the spiny-branched ocotillo, which produces leaves during wet periods and sheds them during dry periods.

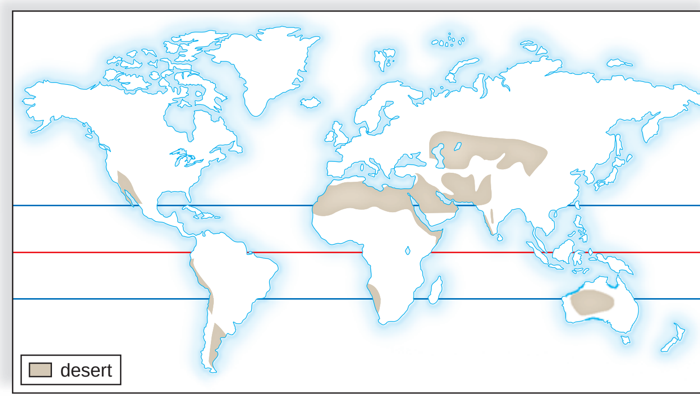
Some animals are adapted to the desert environment. To conserve water, many desert animals such as reptiles and insects are nocturnal or burrowing and have a protective outer body covering. A desert has numerous insects, which pass through the stages of development in synchrony with the periods of rain. Reptiles, especially lizards and snakes, are perhaps the most characteristic group of vertebrates found in deserts, but running birds (e.g., the roadrunner) and rodents (e.g., the kangaroo rat) are also well known (Fig. 46.14*b*). Larger mammals, such as the kit fox, prey on the rodents, as do hawks.

Check Your Progress 46.2

1. Contrast the vegetation of the tropical rain forest with that of a temperate deciduous forest.
2. Account for why there are more predaceous carnivores on the African savanna than in the tundra.

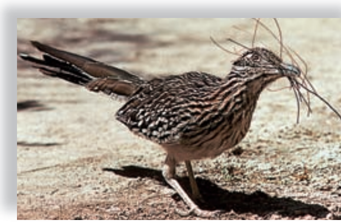
FIGURE 46.14 The desert.

Plants and animals that live in a desert are adapted to arid conditions. **a.** The plants are either succulents, which retain moisture, or shrubs with woody stems and small leaves, which lose little moisture. **b.** Among the animal life, the kangaroo rat feeds on seeds and other vegetation; the roadrunner preys on insects, lizards, and snakes. The kit fox is a desert carnivore.



a. Desert vegetation and location (light brown)

Bannertail kangaroo rat, *Dipodomys spectabilis*



Greater roadrunner, *Geococcyx californianus*

Kit fox, *Vulpes velox*

b. Animal life of desert biome

46.3 Aquatic Ecosystems

Aquatic ecosystems are classified as two types: freshwater (inland) or saltwater. Brackish water, however, is a mixture of fresh and salt water. Figure 46.15 shows how these ecosystems are joined physically and discusses some of the organisms that are adapted to live in them.

In the water cycle, the sun's rays cause seawater to evaporate, and the salts are left behind. As discussed in Chapter 45, the evaporated fresh water rises into the atmosphere, cools, and falls as rain. When rain falls, some of the water sinks, or percolates, into the ground and saturates the Earth to a certain level. The top of the saturation zone is called the groundwater table, or simply the water table.

Since land lies above sea level, gravity eventually returns all fresh water to the sea, but in the meantime, it is contained as standing water within basins, called lakes and ponds, or as flowing water within channels, called streams or rivers. Sometimes groundwater is also located in underground rivers called aquifers. Whenever the Earth contains basins or channels, water will appear to the level of the water table.

Wetlands are areas that are wet for at least part of the year. Generally, wetlands are classified by their vegetation. **Marshes** are wetlands that are frequently or continually inundated by water and characterized by the presence of rushes, reeds, and other grasses. They provide excellent habitat for waterfowl and small mammals. Marshes are one of the most productive ecosystems on Earth. **Swamps** are wetlands that are dominated by either woody plants or shrubs. Common swamp trees include cypress, red maple, and tupelo. The American alligator is a top predator in many swamp ecosystems. **Bogs** are wetlands that are characterized by acidic waters, peat deposits, and sphagnum moss. Bogs receive most of their water from precipitation and are nutrient-poor. Several species of plants thrive in bogs, including cranberries, orchids, and insectivorous plants such as Venus flytraps and pitcher plants. Moose and a number of other animals are inhabitants of bogs in the northern United States and Canada.

Humans have historically channeled aboveground rivers and filled in wetlands with the attitude that useless land was being improved. However, these activities degrade ecosystems, can cause seasonal flooding, and wetlands provide food and habitats for many unique fishes, waterfowl, and other wildlife. They also purify waters by filtering them and by diluting and breaking down toxic wastes and excess nutrients. Wetlands directly absorb storm waters and also absorb overflows from lakes and rivers. In this way, they protect farms, cities, and towns from the devastating effects of floods. Federal and local laws have been enacted for the protection of wetlands, and the current attitude of many has changed.

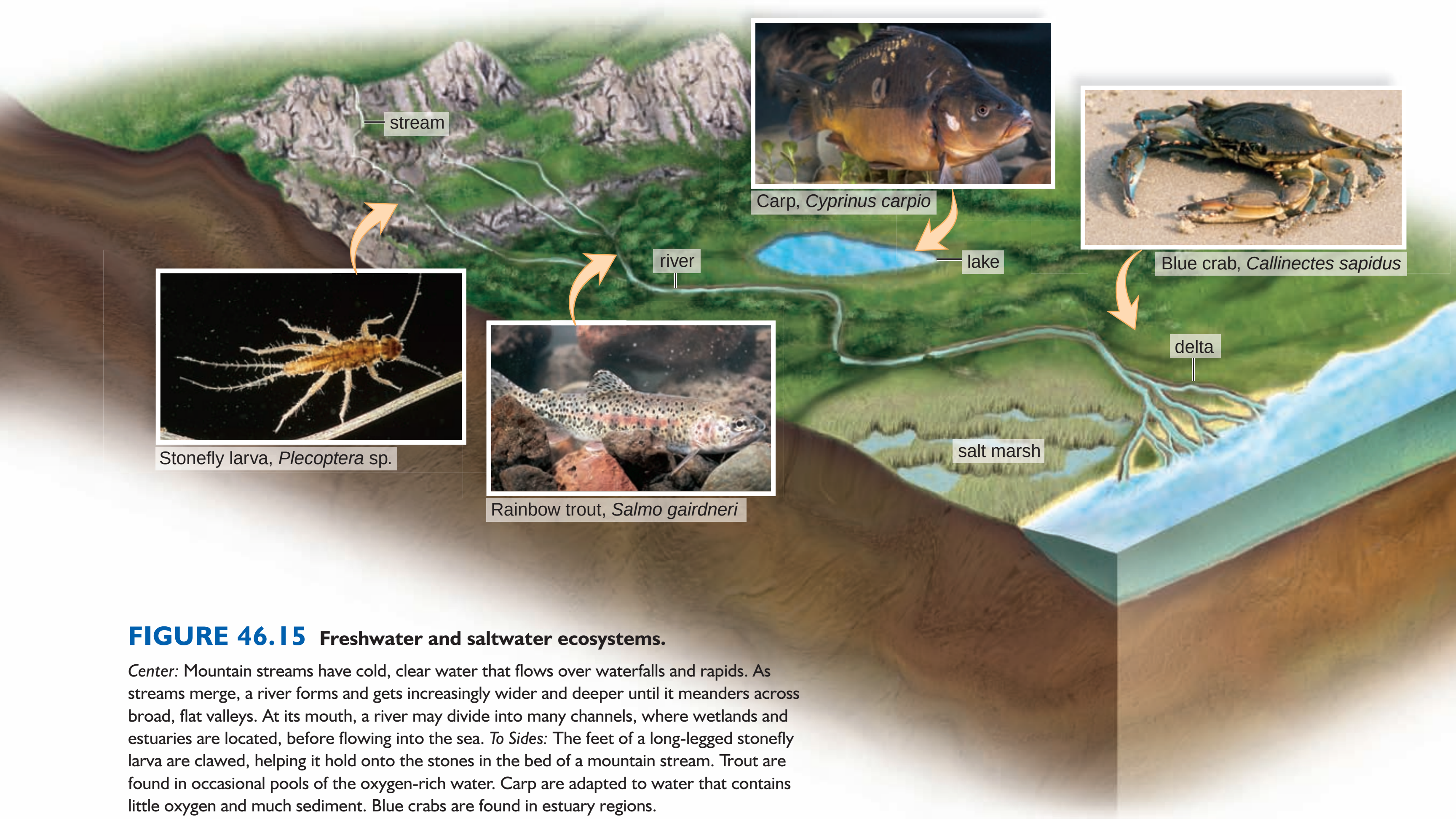
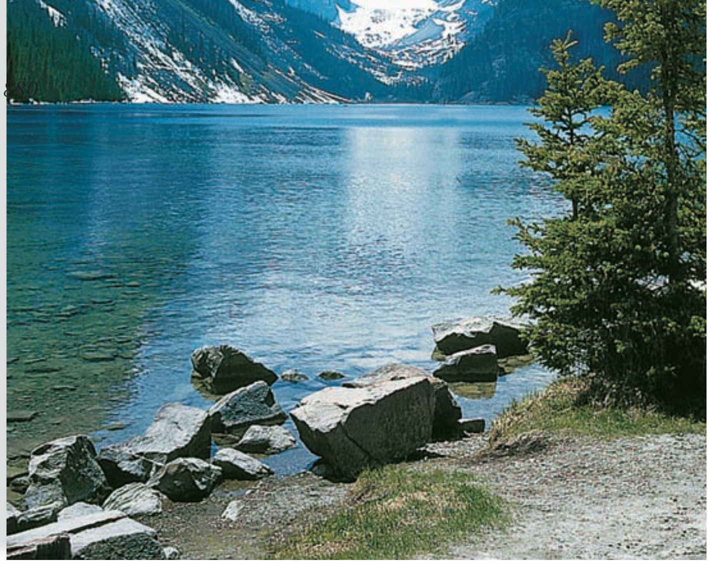


FIGURE 46.15 Freshwater and saltwater ecosystems.

Center: Mountain streams have cold, clear water that flows over waterfalls and rapids. As streams merge, a river forms and gets increasingly wider and deeper until it meanders across broad, flat valleys. At its mouth, a river may divide into many channels, where wetlands and estuaries are located, before flowing into the sea. *To Sides:* The feet of a long-legged stonefly larva are clawed, helping it hold onto the stones in the bed of a mountain stream. Trout are found in occasional pools of the oxygen-rich water. Carp are adapted to water that contains little oxygen and much sediment. Blue crabs are found in estuary regions.



a. Oligotrophic lake

b. Eutrophic lake

FIGURE 46.16 Types of lakes.

Lakes can be classified according to whether they are (**a**) oligotrophic (nutrient-poor) or (**b**) eutrophic (nutrient-rich). Eutrophic lakes tend to have large populations of algae and rooted plants, resulting in a large population of decomposers that use up much of the oxygen and leave little oxygen for fishes.

Lakes

Lakes are bodies of fresh water often classified by their nutrient status. Oligotrophic (nutrient-poor) lakes are characterized by a small amount of organic matter and low productivity (Fig. 46.16*a*). Eutrophic (nutrient-rich) lakes are characterized by plentiful organic matter and high productivity (Fig. 46.16*b*). Such lakes are usually situated in naturally nutrient-rich regions or are enriched by agricultural or urban and suburban runoff. Oligotrophic lakes can become eutrophic through large inputs of nutrients. This process is called **eutrophication.**

In the temperate zone, deep lakes are stratified in the summer and winter and have distinct vertical zones. In summer, lakes in the temperate zone have three layers of water that differ in temperature (Fig. 46.17). The surface layer, the epilimnion, is warm from solar radiation; the middle layer, the thermocline, experiences an abrupt drop in temperature; and the lowest layer, the hypolimnion, is cold. These differences in temperature prevent mixing. The warmer, less dense water of the epilimnion "floats" on top of the colder, more dense water of the thermocline, which floats on top of the hypolimnion.

Phytoplankton found in the sunlit epilimnion use up nutrients as they photosynthesize. Photosynthesis releases oxygen, giving this layer a ready supply. Detritus naturally falls by gravity to the bottom of the lake, and there oxygen is used up as decomposition occurs. Decomposition releases nutrients, however. As the season progresses, the epilimnion becomes nutrient-poor, while the hypolimnion begins to be depleted of oxygen.

In the fall, as the epilimnion cools, and in the spring, as it warms, an overturn occurs. In the fall, the upper epilimnion waters become cooler than the hypolimnion waters. This causes the surface water to sink and the deep water to rise. This **fall overturn** continues until the temperature is uniform throughout the lake. At this point, wind aids in the circulation of water so that mixing occurs. Eventually, oxygen and nutrients become evenly distributed.

As winter approaches, the water cools. Ice formation begins at the top, and the ice remains there because ice is less dense than cool water. Ice has an insulating effect, preventing further cooling of the water below. This permits aquatic organisms to live through the winter in the water beneath the surface of the ice.

In the spring, as the ice melts, the cooler water on top sinks below the warmer water on the bottom. This

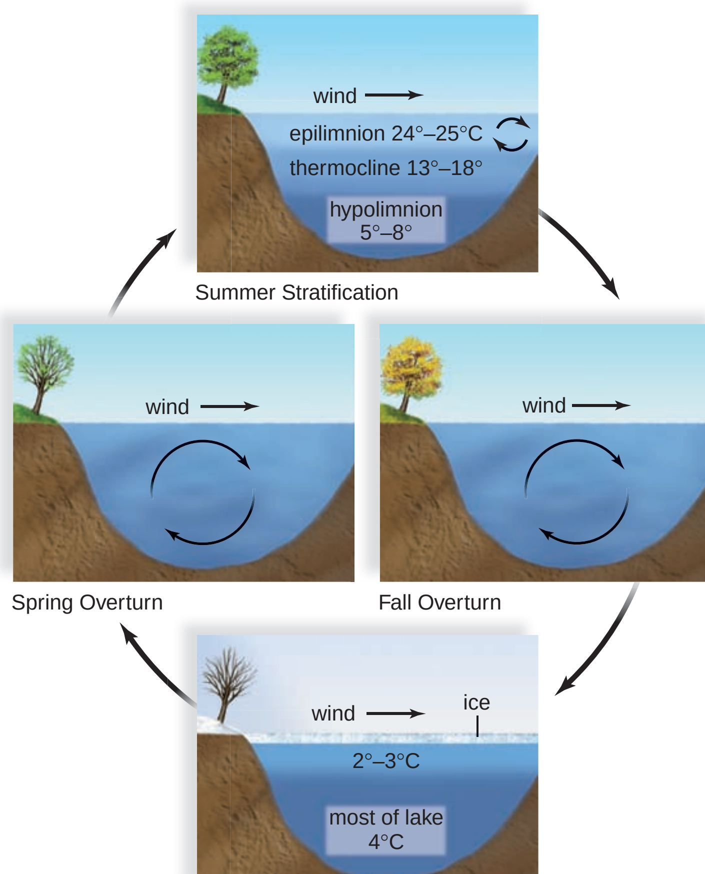


FIGURE 46.17 Lake stratification in a temperate region.

Temperature profiles of a large oligotrophic lake in a temperate region vary with the season. During the spring and fall overturns, the deep waters receive oxygen from surface waters, and surface waters receive inorganic nutrients from deep waters.

spring overturn continues until the temperature is uniform throughout the lake. At this point, wind aids in the circulation of water as before. When the surface waters absorb solar radiation, thermal stratification occurs once more.

The vertical stratification and seasonal change of temperatures in a lake influence the seasonal distribution of fish and other aquatic life in the lake basin. For example, coldwater fish move to the deeper water in summer and inhabit the upper water in winter. In the fall and spring just after mixing occurs, phytoplankton growth at the surface is most abundant.

Life Zones

In both fresh and salt water, free-drifting microscopic organisms, called *plankton* [Gk. *planktos,* wandering], are important components of the ecosystem. **Phytoplankton** [Gk. *phyton,* plant, and *planktos,* wandering] are photosynthesizing algae that become noticeable when a green scum or red tide appears on the water. **Zooplankton** [Gk. *zoon,* animal, and *planktos,* wandering] are minute animals that feed on the phytoplankton. Lakes and ponds can be divided into several life zones (Fig. 46.18). The *littoral zone* is closest to the shore, the *limnetic zone* forms the sunlit body of the lake, and the *profundal zone* is below the level of light penetration. The *benthic zone* includes the sediment at the soil-water interface. Aquatic plants are rooted in the shallow littoral zone of a lake, providing habitat for numerous protozoans, invertebrates, fishes, and some reptiles. Pike are largemouth bass that are "lurking perdators." They wait among vegetation around the margins of lakes and surge out to capture passing prey. Wading birds are commonly seen feeding in the littoral zone. Some organisms, such as the water strider, live at the water-air interface and can literally walk on water. In the limnetic zone, small fishes, such as minnows and killifish, feed on plankton and also serve as food for larger fish, such as bass. In the profundal zone, zooplankton, invertebrates, and fishes such as catfish and whitefish feed on debris that falls from higher zones.

The bottom of the lake is known as the benthic zone. Primarily, the benthic zone is composed of silt, sand, inorganic sediment, and dead organic material (detritus). Bottom-dwelling organisms are known as benthic species and include worms, snails, clams, crayfishes, and some insect larvae. Decomposers, such as bacteria, are also found in the benthic zone and serve to break down wastes and dead organisms into nutrients that are eventually used by producers.

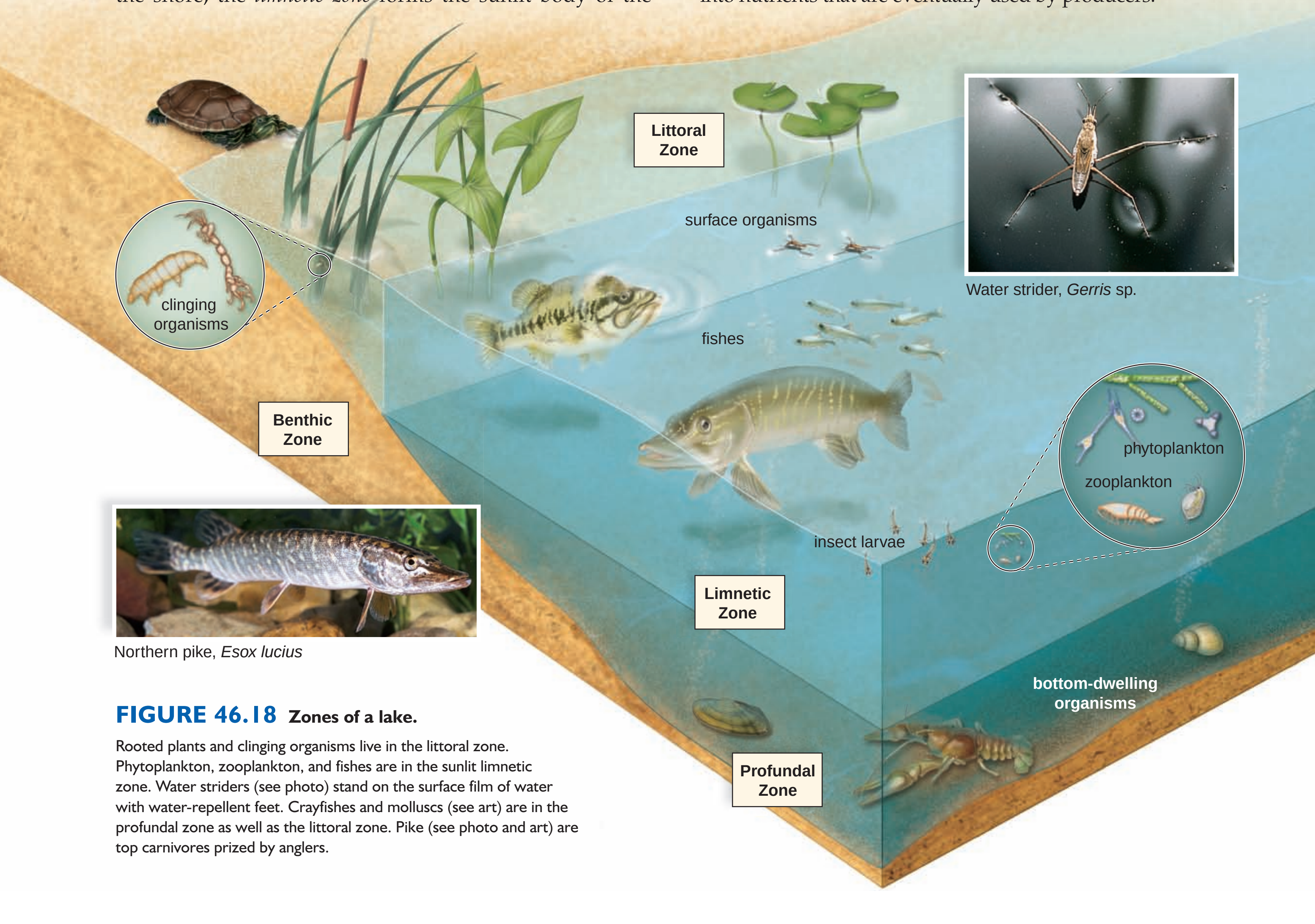


FIGURE 46.18 Zones of a lake.

Rooted plants and clinging organisms live in the littoral zone. Phytoplankton, zooplankton, and fishes are in the sunlit limnetic zone. Water striders (see photo) stand on the surface film of water with water-repellent feet. Crayfishes and molluscs (see art) are in the profundal zone as well as the littoral zone. Pike (see photo and art) are top carnivores prized by anglers.

Coastal Ecosystems Border the Oceans

Salt marshes, discussed previously, and also mudflats and mangrove swamps, featured in Figure 46.19, are ecosystems that occur at a delta. Mangrove swamps develop in subtropical and tropical zones, while marshes and mudflats occur in temperate zones. These ecosystems are often designated as an estuary. So are coastal bays, fjords (an inlet of water between high cliffs), and some lagoons (a body of water separated from the sea by a narrow strip of land). Therefore, the term estuary has a very broad definition. An **estuary** is a partially enclosed body of water where fresh water and seawater meet and mix as a river enters the ocean.

Organisms living in an estuary must be able to withstand constant mixing of waters and rapid changes in salinity. But those organisms adapted to the estuarine environment find an abundance of nutrients. An estuary acts as a nutrient trap because the sea prevents the rapid escape of nutrients brought by a river. As the result of usually warm, calm waters and plentiful nutrients, estuaries are biologically diverse and highly productive.

Phytoplankton and shore plants thrive in the nutrient-rich estuaries, providing an abundance of food and habitat for animals. It is estimated that nearly two-thirds of marine fishes and shellfish spawn and develop in the protective and rich environment of estuaries, making the estuarine environment the nursery of the sea. An abundance of larval, juvenile, and mature fish and shellfish attract a number of predators, such as reptiles, birds, and fishes of various types.

Rocky shores (Fig. 46.19*c*) and sandy shores are constantly bombarded by the sea as the tides roll in and out. The **intertidal zone** lies between the high- and low-tide marks (Fig. 46.20). In the upper portion of the intertidal zone, barnacles are glued so tightly to the stone by their own secretions that their calcareous outer plates remain in place, even after the enclosed shrimplike animal dies. In the midportion of the intertidal zone, brown algae, known as rockweed, may overlie the barnacles. Below the intertidal zone, macroscopic seaweeds, which are the main photosynthesizers, anchor themselves to the rocks by holdfasts.

Organisms cannot attach themselves to shifting, unstable sands on a sandy beach; therefore, nearly all the permanent residents dwell underground. They either burrow during the day and surface to feed at night, or they remain permanently within their burrows and tubes. Ghost crabs and sandhoppers (amphipods) burrow themselves above the high-tide mark and feed at night when the tide is out. Sandworms and sand (ghost)

FIGURE 46.19 Coastal ecosystems.

a. Mudflats are frequented by migrant birds. **b.** Mangrove swamps skirt the coastlines of many tropical and subtropical lands. **c.** Some organisms of a rocky coast live in tidal pools.

a. Mudflat

b. Mangrove swamp

c. Rocky shore

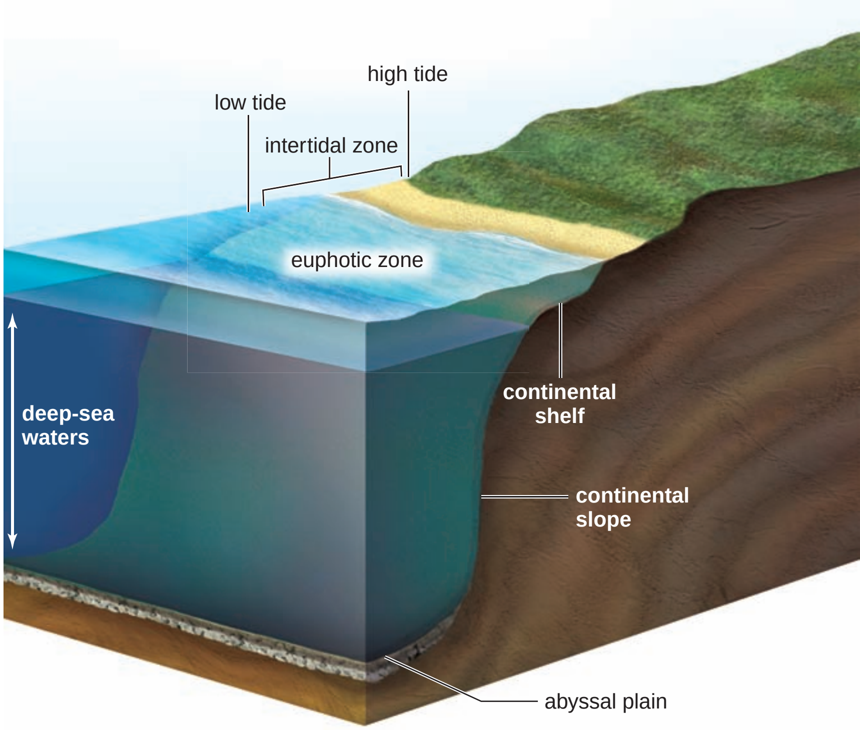


FIGURE 46.20 Ocean ecosystems.

Organisms live in the well-lit waters of the euphotic zone and in the increasing darkness of the deep-sea waters of the pelagic zones (see Figure 46.21).

shrimp remain within their burrows in the intertidal zone and feed on detritus whenever possible. Still lower in the sand, clams, cockles, and sand dollars are found. A variety of shorebirds visit the beaches and feed on various invertebrates and fishes.

Oceans

Shallow ocean waters (called the *euphotic zone*) contain a greater concentration of organisms than the rest of the sea (see Fig. 46.20). Here, phytoplankton, (i.e., algae) is food not only for zooplankton (i.e., protozoans and microscopic animals) but also for small fishes. These attract a number of predatory and commercially valuable fishes. On the continental shelf, seaweed can be found growing, even on outcroppings as the water gets deeper. Clams, worms, and sea urchins are preyed upon by sea stars, lobsters, crabs, and brittle stars.

Coral reefs are areas of biological abundance just below the surface in shallow, warm, tropical waters. Their chief constituents are stony corals, animals that have a calcium carbonate (limestone) exoskeleton, and calcareous red and green algae. Corals provide a home for microscopic algae called *zooxanthellae*. The corals, which feed at night, and the algae, which photosynthesize during the day, are mutualistic and share materials and nutrients. The algae need sunlight, and this may be the reason coral reefs form only in shallow, sunlit waters.

A reef is densely populated with life. The large number of crevices and caves provide shelter for filter feeders (sponges, sea squirts, and fanworms) and for scavangers (crabs and sea urchins). The barracuda, moray eel, and shark are top predators in coral reefs. There are many types of small, beautifully colored fishes. These become food for larger fishes, including snappers that are caught for human consumption.

Most of the ocean lies within the **pelagic zones,** as noted in Figure 46.21. The *epipelagic zone* lacks the inorganic nutrients of shallow waters, and therefore it does not have as high a concentration of phytoplankton, even though the surface is sunlit. Still, the photosynthesizers are food for a large assembly of zooplankton, which then become food for schools of various fishes. A number of porpoise and dolphin species visit and feed in the epipelagic zone. Whales, too, are mammals found in this zone. Baleen whales strain krill (small crustaceans) from the water, and toothed sperm whales feed primarily on the common squid.

Animals in the deeper waters of the *mesopelagic zone* are carnivores, which are adapted to the absence of light, and tend to be translucent, red colored, or even luminescent. There are luminescent shrimps, squids, and fishes, including lantern and hatchet fishes. Various species of zooplankton, invertebrates, and fishes migrate from the mesopelagic zone to the surface to feed at night.

The deepest waters of the *bathypelagic zone* are in complete darkness except for an occasional flash of bioluminescent light. Carnivores and scavengers are found in this zone. Strange-looking fishes with distensible mouths and abdomens and small, tubular eyes feed on infrequent prey.

It once was thought that few vertebrates exist on the *abyssal plain* beneath the bathypelagic zone because of the intense pressure and the extreme cold. Yet, many invertebrates survive there by feeding on debris floating down from the mesopelagic zone. Sea lilies (crinoids) rise above the seafloor; sea cucumbers and sea urchins crawl around on the sea bottom; and tube worms burrow in the mud.

The flat abyssal plain is interrupted by enormous underwater mountain chains called oceanic ridges. Along the axes of the ridges, crustal plates spread apart, and molten magma rises to fill the gap. At **hydrothermal vents,** seawater

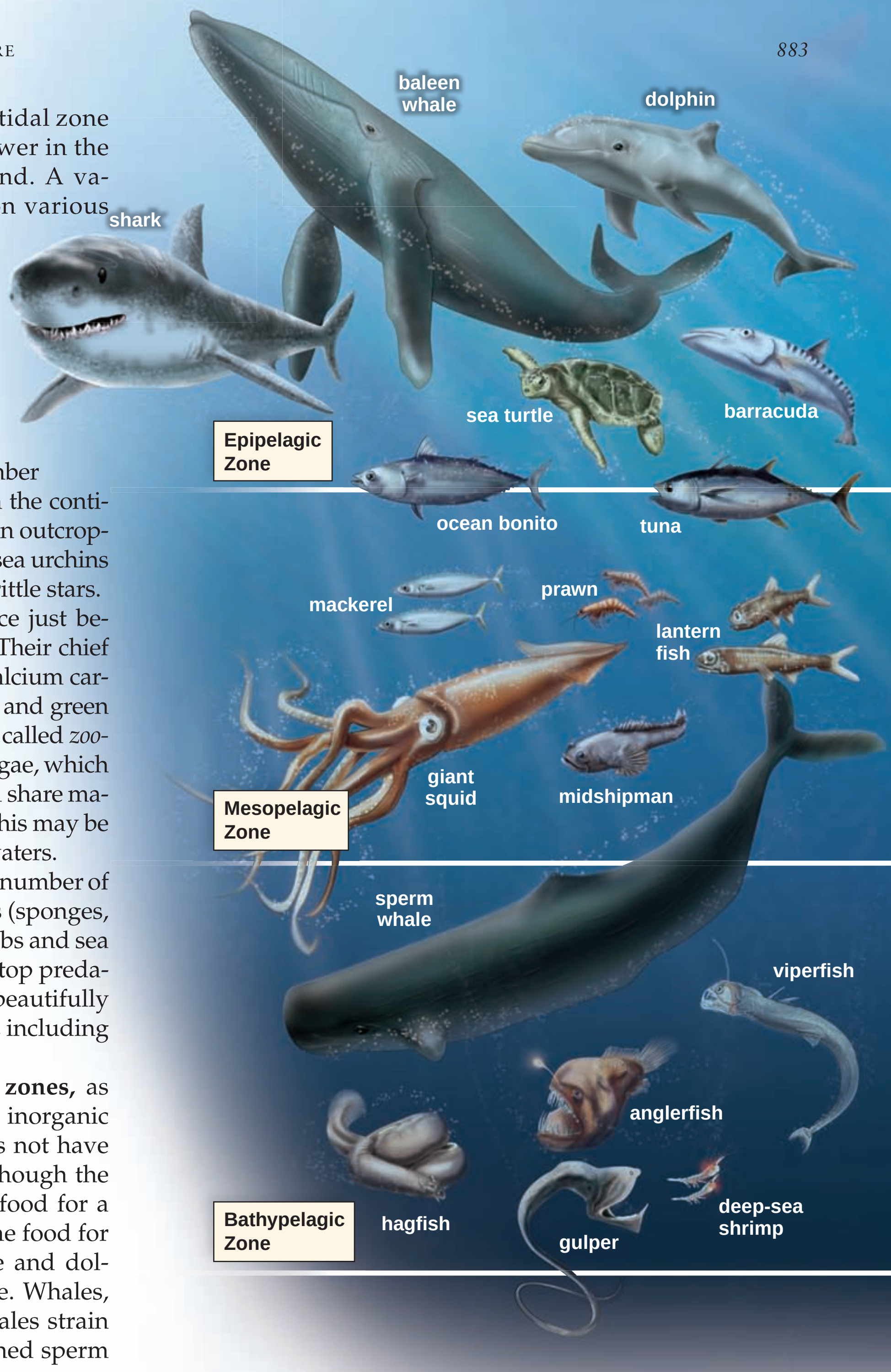


FIGURE 46.21 **Ocean inhabitants of pelagic zones.**
Different organisms are characteristic of the epipelagic, mesopelagic, and bathypelagic zones.

percolates through cracks and is heated to about 350°C, causing sulfate to react with water and form hydrogen sulfide (H_2S). Chemoautotrophic bacteria that obtain energy from oxidizing hydrogen sulfide exist freely or mutualistically within the tissues of organisms. They are the start of food chains for an ecosystem that includes huge tube worms, clams, crustaceans, echinoderms, and fishes. This ecosystem can exist where light never penetrates because, unlike photosynthesis, chemosynthesis does not require light energy.

Ocean Currents

Climate is driven by the sun, but the oceans play a major role in redistributing heat in the biosphere. Water tends to be warm at the equator and much cooler at the poles because of the distribution of the sun's rays, as discussed earlier (see Fig. 46.1*a*). Air takes on the temperature of the water below, and warm air moves from the equator to the poles. In other words, the oceans make the winds blow. (Landmasses also play a role, but the oceans hold heat longer and remain cool longer during periods of changing temperature than do continents.)

When wind blows strongly and steadily across a great expanse of ocean for a long time, friction from the moving air begins to drag the water along with it. Once the water has been set in motion, its momentum, aided by the wind, keeps it moving in a steady flow called a current. Because the ocean currents eventually strike land, they move in a circular path—clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere (Fig. 46.22). As the currents flow, they take warm water from the equator to the poles. One such current, called the Gulf Stream, brings tropical Caribbean water to the east coast of North America and the higher latitudes of western Europe. Without the Gulf Stream, Great Britain, which has a relatively warm temperature, would be as cold as Greenland. In the Southern Hemisphere, another major ocean current warms the eastern coast of South America.

Also in the Southern Hemisphere, a current called the Humboldt Current flows toward the equator. The Humboldt Current carries phosphorus-rich cold water northward along the west coast of South America. During a process called **upwelling,** cold offshore winds cause cold nutrient-rich waters to rise and take the place of warm nutrient-poor waters. In South America, the enriched waters cause an abundance of marine life that supports the fisheries of Peru and northern Chile. Birds feeding on these organisms deposit their droppings on land, where they are mined as guano, a commercial source of phosphorus. When the Humboldt Current is not as cool as usual, upwelling does not occur, stagnation results, the fisheries decline, and climate patterns change globally. This phenomenon, which is discussed in the Ecology Focus on page 885, is called an **El Niño–Southern Oscillation.**

Check Your Progress 46.3

1. Describe the zones of the open ocean.

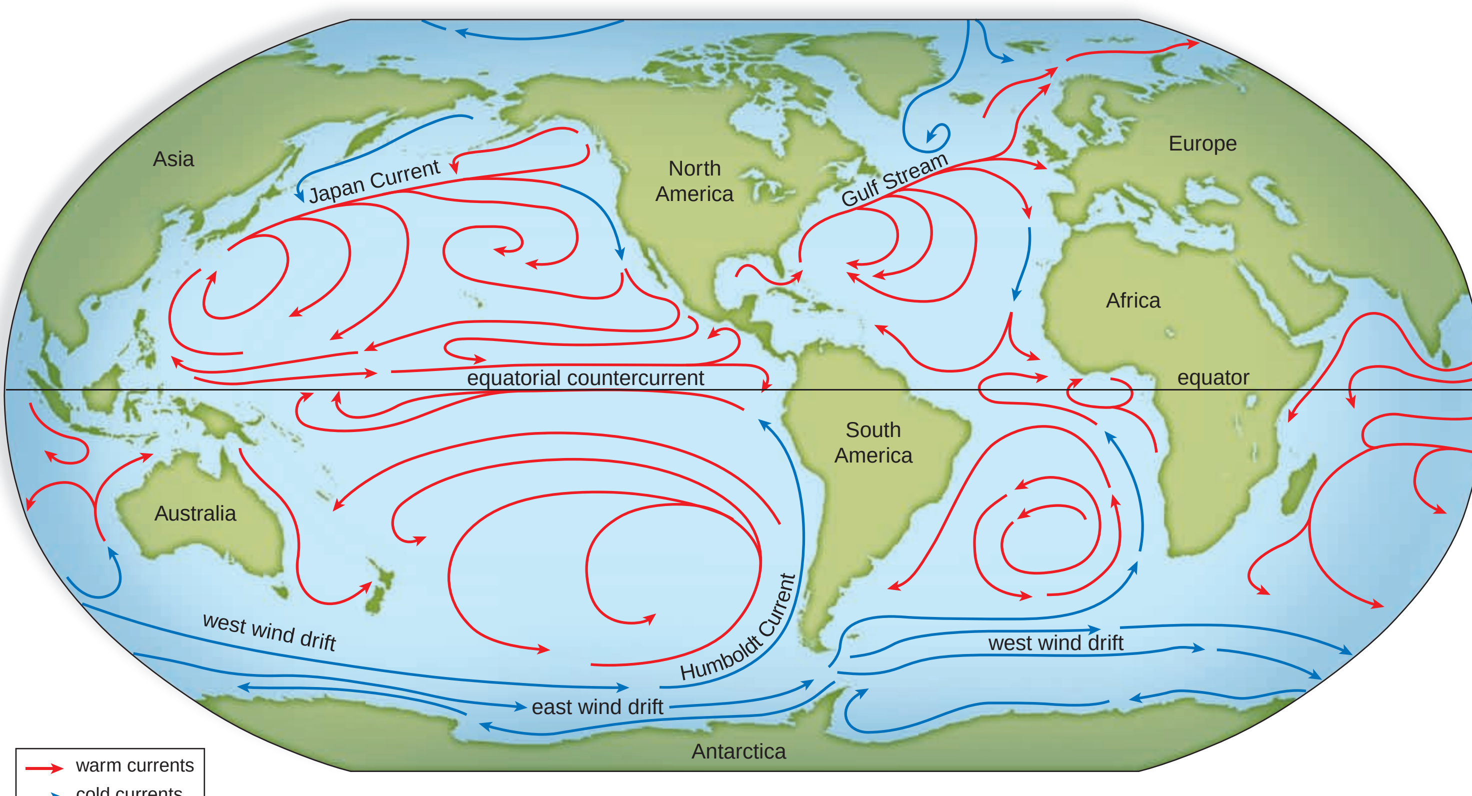


FIGURE 46.22 **Ocean currents.**

The arrows on this map indicate the locations and directions of the major ocean currents set in motion by the global wind circulation. By carrying warm water to cool latitudes (e.g., the Gulf Stream) and cool water to warm latitudes (e.g., the Humboldt Current), these currents have a major effect on the world's climates.

ecology focus

El Niño–Southern Oscillation

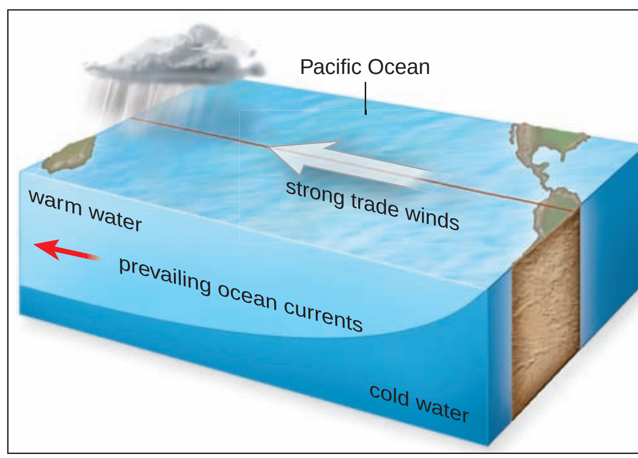
Climate largely determines the distribution of life on Earth. Short-term variations in climate, which we call weather, also have a pronounced effect on living things. There is no better example than an El Niño. Originally, El Niño referred to a warming of the seas off the coast of Peru at Christmastime—hence, the name El Niño, "the boy child," for the Christ child Jesus.

Now scientists prefer the term El Niño–Southern Oscillation (ENSO) for a severe weather change brought on by an interaction between the atmosphere and ocean currents. Ordinarily, the southeast trade winds move along the coast of South America and turn west because of the Earth's daily rotation on its axis. As the winds drag warm ocean waters from east to west, there is an upwelling of nutrient-rich cold water from the ocean's depths, resulting in a bountiful Peruvian harvest of anchovies. When the warm ocean waters reach their western destination, the monsoons bring rain to India and Indonesia. Scientists have noted that these events correlate with a difference in the barometric pressure over the Indian Ocean and the southeastern Pacific—that is, the barometric pressure is low over the Indian Ocean and high over the southeastern Pacific. But when a "southern oscillation" occurs and the barometric pressures switch, an El Niño begins.

During an El Niño, both the northeast and the southeast trade winds slacken. Upwelling no longer occurs, and the anchovy catch off the coast of Peru plummets. During a severe El Niño, waters from the east never reach the west, and the winds lose their moisture in the middle of the Pacific instead of over the Indian Ocean. The monsoons fail, and drought occurs in India, Indonesia, Africa, and Australia. Harvests decline, cattle must be slaughtered, and famine is likely in highly populated India and Africa, where funds to import replacement supplies of food are limited.

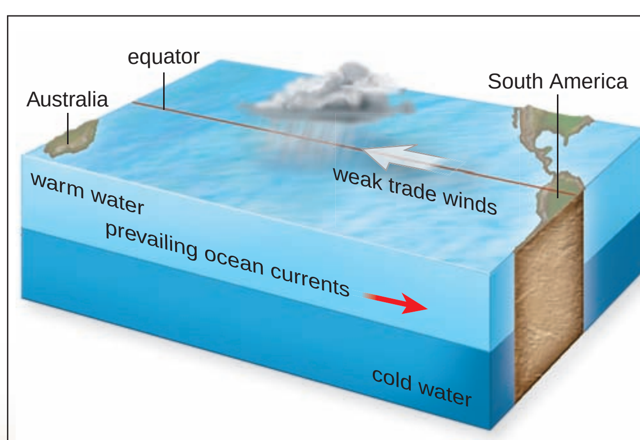
A backward movement of winds and ocean currents may even occur so that the waters warm to more than 14° above normal along the west coast of the Americas. This is a sign that a severe El Niño has occurred, and the weather changes are dramatic in the Americas also. Southern California is hit by storms and even hurricanes, and the deserts of Peru and Chile receive so much rain that flooding occurs. A jet stream (strong wind currents) can carry moisture into Texas, Louisiana, and Florida, with flooding a near certainty. Or the winds can turn northward and deposit snow in the mountains along the west coast so that flooding occurs in the spring. Some parts of the United States, however, benefit from an El Niño. The Northeast is warmer than usual, few if any hurricanes hit the east coast, and there is a lull in tornadoes throughout the Midwest. Altogether, a severe El Niño affects the weather over three-quarters of the globe.

Eventually, an El Niño dies out, and normal conditions return. The normal cold-water state off the coast of Peru is known as La Niña (the girl). Figure 46B contrasts the weather conditions of a La Niña with those of an El Niño. Since 1991, El Niños have varied in magnitude, and two record-breaking El Niños have occurred. As our overall climate changes, the severity of El Niños remains somewhat unpredictable.



La Niña

- Upwelling off the west coast of South America brings cold waters to the surface.
- Barometric pressure is high over the southeastern Pacific.
- Monsoons associated with the Indian Ocean occur.
- Hurricanes occur off the east coast of the United States.



El Niño

- Great ocean warming occurs off the west coast of the Americas.
- Barometric pressure is low over the southeastern Pacific.
- Monsoons associated with the Indian Ocean fail.
- Hurricanes occur off the west coast of the United States.

FIGURE 46B La Niña (*above*) and El Niño (*below*).

Connecting the Concepts

The biosphere is the product of interactions of living organisms with the Earth's physical and chemical environment over billions of years. Life has affected the atmosphere, modifying its composition and influencing global climate. Organisms have helped establish the chemical and physical conditions of streams, lakes, and oceans. The soils of terrestrial ecosystems and the sediments of aquatic ecosystems are structured largely by the activities of organisms. Reef-building plants and animals have helped build the islands on which millions of humans live. The Earth's diverse biomes also result from interactions of the biotic communities and the abiotic environment.

Over geological time, the biosphere has been changing constantly. The biomes of the age of dinosaurs were strikingly different from those of today. Astrophysical events have triggered some of this change. Changes in the sun's radiation output and in the tilt of the Earth's axis have altered the pattern of solar energy reaching the Earth's surface. Geological processes have also modified conditions for life. The drifting of continents has changed the arrangement of continents and oceans. Mountain ranges have been thrust up and eroded down. Through these changing conditions, life has evolved, and the structure of the Earth's biomes has evolved as well. In the last few million years, humans appeared and learned to exploit the Earth's biomes.

Humans have transformed vast areas of many of the terrestrial biomes into farmland, cities, highways, and other developments. Still, people depend on the biodiversity that exists in the Earth's biomes, and on the interactions of other organisms within the biosphere. These interactions influence nutrient cycling, waste processing, and basic biological productivity. However, the Earth's biotic diversity also provides enjoyment and inspiration to millions of people, who spend billions of dollars to visit coral reefs, deserts, rain forests, and even the Arctic tundra.

summary

46.1 Climate and the Biosphere

Because the Earth is a sphere, the sun's rays at the poles are distributed out over a larger area than the direct rays at the equator. The temperature at the surface of the Earth therefore decreases from the equator to each pole. The Earth is tilted on its axis, and the seasons change as the Earth revolves annually around the sun.

Warm air rises near the equator, loses its moisture, and then descends at about 30° north and south latitude to the poles. When the air descends, it absorbs moisture from the land, and therefore the great deserts of the world are formed at 30° latitudes. Because the Earth rotates on its axis daily, the winds blow in opposite directions above and below the equator. Topography also plays a role in the distribution of moisture. Air rising over coastal ranges loses its moisture on the windward side, making the leeward side arid.

46.2 Terrestrial Ecosystems

A biome is a major type of terrestrial community. Biomes are distributed according to climate—that is, temperature and rainfall influence the pattern of biomes about the world. The effect of temperature causes the same sequence of biomes when traveling to northern latitudes as when traveling up a mountain.

The Arctic tundra is the northernmost biome and consists largely of short grasses, sedges, and dwarf woody plants. Because of cold winters and short summers, most of the water in the soil is frozen year-round. This is called the permafrost.

The taiga, a coniferous forest, has less rainfall than other types of forests. The temperate deciduous forest has trees that gain and lose their leaves because of the alternating seasons of summer and winter. Tropical rain forests are continually warm and wet. These are the most complex and productive of all biomes.

Shrublands usually occur along coasts that have dry summers and receive most of their rainfall in the winter. Among grasslands, the savanna, a tropical grassland, supports the greatest number of different types of large herbivores. Temperate grasslands, such as that found in the central United States, have a limited variety of vegetation and animal life.

Deserts are characterized by a lack of water—they are usually found in places with less than 25 cm of precipitation per year. Some desert plants, such as cacti, are succulents with thick stems and leaves, and others are shrubs that are deciduous during dry periods.

46.3 Aquatic Ecosystems

Streams, rivers, lakes, and wetlands are different freshwater ecosystems. In deep lakes of the temperate zone, the temperature and the concentration of nutrients and gases in the water vary with depth. The entire body of water is cycled twice a year, distributing nutrients from the bottom layers. Lakes and ponds have three life zones. Rooted plants and clinging organisms live in the littoral zone, plankton and fishes live in the sunlit limnetic zone, and bottom-dwelling organisms such as crayfishes and molluscs live in the profundal zone.

Marine ecosystems are divided into coastal ecosystems and the oceans. The coastal ecosystems, especially estuaries, are more productive than the oceans. Estuaries (and associated salt marshes, mudflats, and mangrove forests) are near the mouth of a river. Estuaries are considered the nurseries of the sea.

An ocean is divided into the pelagic zone and the ocean floor. The pelagic zone (open waters) has three zones. The epipelagic zone receives adequate sunlight and supports the most life. The mesopelagic zone contains organisms adapted to minimum or no light. The bathypelagic zone is in complete darkness. The ocean floor includes the continental shelf, the continental slope, and the abyssal plain.

understanding the terms

montane coniferous forest 869
pelagic zone 883
permafrost 870
phytoplankton 881
rain shadow 867
savanna 876
shrubland 876
spring overturn 881
swamp 879
taiga 871
temperate deciduous forest 872
temperate rain forest 871
topography 867
tropical rain forest 874
upwelling 884
wetland 879
zooplankton 881

Match the terms to these definitions:

a. _______________ End of a river where fresh water and salt water mix as they meet.
b. _______________ Open portion of the sea.
c. _______________ Terrestrial biome that is a coniferous forest extending in a broad belt across northern Eurasia and North America.
d. _______________ Terrestrial biome that is a grassland in Africa, characterized by few trees and a severe dry season.
e. _______________ Oxygen-rich top waters mix with nutrient-rich bottom waters in stratified lakes.

reviewing this chapter

1. Describe how a spherical Earth and the path of the Earth about the sun affect climate. 866
2. Describe the air circulation about the Earth, and tell why deserts are apt to occur at 30° north and south of the equator. 866
3. How does a coastal mountain range affect climate? What causes a monsoon climate? 867
4. Name the terrestrial biomes you would expect to find when going from the base to the top of a mountain. 869
5. Describe the location, the climate, and the populations of the Arctic tundra, coniferous forests (both taiga and temperate rain forest), temperate deciduous forests, tropical rain forests, shrublands, grasslands (both temperate grasslands and savanna), and deserts. 870–78
6. Describe the importance of wetlands and the major types of wetlands. 879
7. Describe the overturn of a temperate lake, the life zones of a lake, and the organisms you would expect to find in each life zone. 880–81
8. Describe the coastal communities, and discuss the importance of estuaries to the productivity of the ocean. 882–83
9. Describe the zones of the open ocean and the organisms you would expect to find in each zone. 883–84
10. Describe the ocean currents and how the Gulf Stream accounts for Great Britain having a mild temperature. 884

testing yourself

Choose the best answer for each question.

1. The seasons are best explained by
   a. the distribution of temperature and rainfall in biomes.
   b. the tilt of the Earth as it orbits about the sun.
   c. the daily rotation of the Earth on its axis.
   d. the fact that the equator is warm and the poles are cold.
2. The mild climate of Great Britain is best explained by
   a. the winds called the westerlies.
   b. the spinning of the Earth on its axis.
   c. Great Britain being a mountainous country.
   d. the flow of ocean currents.
3. Which of these pairs is mismatched?
   a. tundra—permafrost
   b. savanna—*Acacia* trees
   c. prairie—epiphytes
   d. coniferous forest—evergreen trees
4. All of these phrases describe the tundra except
   a. low-lying vegetation.
   b. northernmost biome.
   c. short growing season.
   d. many different types of species.
5. The forest with a multilevel canopy is the
   a. tropical rain forest.
   b. coniferous forest.
   c. tundra.
   d. temperate deciduous forest.
6. Why are lush evergreen forests present in the Pacific Northwest of the United States?
   a. The rotation of the Earth causes this.
   b. Winds blow from the ocean, bringing moisture.
   c. They are located on the leeward side of a mountain range.
   d. Both b and c are correct.
   e. All of these are correct.
7. Which of these influences the location of a particular biome?
   a. latitude
   b. average annual rainfall
   c. average annual temperature
   d. altitude
   e. All of these are correct.
8. Which of these is a function of a wetland?
   a. purifies water
   b. is an area where toxic wastes can be broken down
   c. helps absorb overflow and prevents flooding
   d. is a home for organisms that are links in food chains
   e. All of these are correct.
9. The area of a lake closest to shore and where rooted plants are found is the
   a. littoral zone.
   b. limnetic zone.
   c. profundal zone.
   d. benthic zone.
10. An estuary acts as a nutrient trap because of the
    a. action of rivers and tides.
    b. depth at which photosynthesis can occur.
    c. amount of rainfall received.
    d. height of the water table.
11. Which area of an ocean has the most light and nutrients?
    a. epipelagic zone and abyssal plain
    b. epipelagic zone only
    c. benthic zone only
    d. neritic province
12. Which area of the pelagic zone is completely dark?
    a. epipelagic zone
    b. mesopelagic zone
    c. bathypelagic zone
13. Runoff of fertilizer and animal wastes from a large farm that drains into a lake would be an example of which process?
    a. fall overturn
    b. eutrophication
    c. spring overturn
    d. upwelling

14. Phytoplankton are more likely to be found in which life zone of a lake?
    a. limnetic zone
    b. profundal zone
    c. benthic zone
    d. All of these are correct.
15. Which area of the seashore is only exposed during low tide?
    a. upper littoral zone
    b. mid-littoral zone
    c. lower littoral zone
    d. None of these are correct.
16. Which of these would normally be found in the benthic zone of a lake?
    a. minnows
    b. clams
    c. zooplankton
    d. plants
    e. large fish
17. All of the following phrases describe a tropical rain forest, except
    a. nutrient-rich soil.
    b. many arboreal plant and animals.
    c. canopy composed of many layers.
    d. broad-leaved evergreen trees.
18. An oligotrophic lake
    a. is nutrient-rich.
    b. is cold.
    c. is likely to be found in an agricultural or urban area.
    d. has poor productivity.
19. Energy for the food chain near hydrothermal vents comes from
    a. dead organisms that fall down from above.
    b. highly efficient photosynthetic phytoplankton.
    c. chemoautotrophic bacteria.
    d. heat given off by the vents.

thinking scientifically

1. Pharmaceutical companies are interested in "bioprospecting" in tropical rain forests. These companies are looking for naturally occurring compounds in plants or animals that can be used as drugs for a variety of diseases. The most promising compounds act as antibacterial or antifungal agents. Even discounting the fact that the higher density of species in tropical rain forests would produce a wider array of compounds than another biome, why would antibacterial and antifungal compounds be more likely to evolve in this particular biome?
2. When hurricanes come ashore, the ocean tide may surge dozens of feet above normal into coastal communities. Recently, hurricane Katrina had devastating effects on New Orleans, Louisiana, a city actually built below sea level following the draining of the natural wetlands. How would the presence of wetlands possibly decrease the damage of seawater brought in by an incoming hurricane?

bioethical issue

Water Pollution

Agricultural fertilizers are the chief cause of nitrate contamination of drinking-water wells. Excessive nitrates in a baby's bloodstream can lead to slow suffocation, known as blue-baby syndrome. Agricultural herbicides are suspected carcinogens in the tap water of scattered ecosystems coast to coast. What can be done?

Some farmers are already using irrigation methods that deliver water directly to plant roots, no-till agriculture that reduces the loss of topsoil and cuts back on herbicide use, and integrated pest management, which relies heavily on good bugs to kill bad bugs. Perhaps more should do so. Encouraged—in some cases, compelled—by state and federal agents, dairy farmers have built sheds, concrete containments, and underground liquid storage tanks to hold wastes when it rains. Later, the manure is trucked to fields and spread as fertilizer.

Homeowners, like business golf clubs and ski resorts, also contribute to the problem. The manicuring of lawns, the use of motor vehicles, and the construction and use of roads and buildings all add contaminants to streams, lakes, and aquifers. Citizens around Grand Traverse Bay on the eastern shore of Lake Michigan have also gotten the message, especially because they want to keep on enjoying water-dependent activities such as boating, swimming, and fishing. James Haverman, a concerned member of the Traverse Bay Watershed Initiative says, "If we can't change the way people live their everyday lives, we are not going to be able to make a difference." Builders in Traverse County are already required to control soil erosion with filter fences, steer rainwater away from exposed soil, build sediment basins, and plant protective buffers. Presently, homeowners must have a 25-foot setback from wetlands and a 50-foot setback from lakes and creeks. They are also encouraged to pump out their septic systems every two years. Do you approve of legislation that requires farmers and homeowners to protect freshwater supplies? Why or why not?

Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

http://www.mhhe.com/maderbiology10

47

Conservation of Biodiversity

Even schoolchildren on a field trip in the woods may come across many deformed frogs. These frogs often have extra limbs arising from their midsection. Scientists are working to discover why this problem is so widespread and, so far, two hypotheses have been suggested. One hypothesis being studied is that a small trematode burrows into a tadpole and prevents the normal development of legs. The other hypothesis is that a chemical called methoprene, which is used by many farmers as a pesticide, is affecting development and causing these abnormalities. Once the cause is known, something can be done about it.

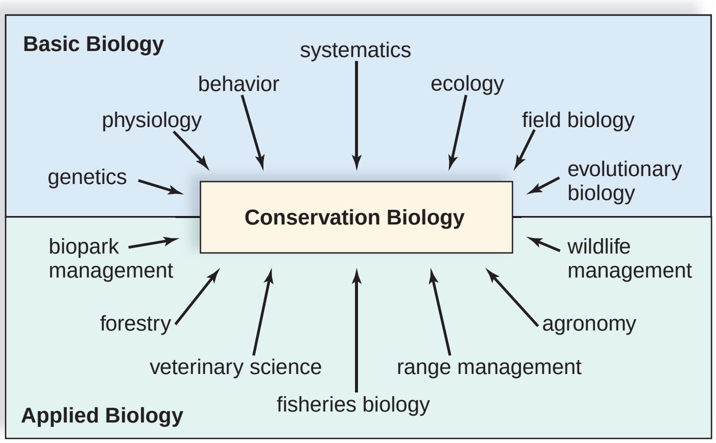
In this chapter, we discuss the emergence of conservation biology as a branch of environmental science directed at actively improving environmental conditions for wildlife and ourselves. Conservation biology examines the nature and evolutionary origin of biodiversity. As an applied science, it studies the human activities that are presently reducing biodiversity and what steps to take to reverse the situation. Conservation biology has an ultimate goal: the preservation and management of ecosystems for human welfare.

Deformed frogs are undoubtedly due to environmental effects.

concepts

47.1 Conservation Biology and Biodiversity

Conservation biology [L. *conservatio,* keep, save] is a relatively new discipline of biology that studies all aspects of biodiversity with the goal of conserving natural resources for this generation and all future generations. Conservation biology is unique in that it is concerned with both the development of scientific concepts and the application of these concepts to the everyday world. A primary goal is the management of biodiversity for sustainable use by humans. To achieve this goal, conservation biologists are interested in, and come from, many subfields of biology that only now have been brought together into a cohesive whole.



Like a physician, a conservation biologist must be aware of the latest findings, both theoretical and practical, and be able to use this knowledge to diagnose the source of trouble and suggest a suitable treatment. Often, it is necessary for conservation biologists to work with government officials at both the local and federal levels. Public education is another important duty of conservation biologists.

Conservation biology is a unique science in another way. It blatantly supports the following ethical principles: (1) Biodiversity is desirable for the biosphere and therefore for humans; (2) extinctions, due to human actions, are therefore undesirable; (3) the complex interactions in ecosystems support biodiversity and are desirable; and (4) biodiversity generated by evolutionary change has value in and of itself, regardless of any practical benefit. The consequences of disrupting ecosystem interactions through biodiversity loss are potentially very large and unpredictable. Therefore, ecosystem disruption should be avoided.

Conservation biology has emerged in response to a crisis—never before in the history of the Earth are so many extinctions expected in such a short period of time. Estimates vary, but at least 10–20% of all species now living most likely will become extinct in the next 20–50 years unless planned coordinated actions are taken. It is urgently important, then, that all citizens understand the concept of biodiversity, the value of biodiversity, the likely causes of present-day extinctions, what could be done to prevent extinctions from occurring, and the potential consequences of decreased biodiversity.

To protect biodiversity, **bioinformatics** is applied. Bioinformatics is the science of collecting, analyzing, and making readily available biological information. Throughout the world, molecular, descriptive, and biogeographical information on organisms is being collected. This information is used in understanding and protecting biodiversity and will become more useful as more data are accumulated.

Biodiversity

At its simplest level, **biodiversity** [Gk. *bio,* life; L. *diversus,* various] is the variety of life on Earth. It is common practice to describe biodiversity in terms of the number of species among various groups of organisms. Figure 47.1 only accounts for the species that have so far been described. It has been estimated that there may be between 10 and 50 million species in all; if so, many species are still to be found and described.

Of these, nearly 1,200 species in the United States and 30,000 species worldwide are in danger of extinction. An **endangered species** is one that is in peril of immediate extinction throughout all or most of its range. Examples of endangered species include the black lace cactus, armored snail, hawksbill sea turtle, California condor, West Indian manatee, and snow leopard. **Threatened species** are organisms that are likely to become endangered species in the foreseeable future. Examples of threatened species include the Navaho sedge, puritan tiger beetle, gopher tortoise, bald eagle, gray wolf, and Louisiana black bear.

To develop a meaningful understanding of life on Earth, we need to know more about species than their total number. Ecologists describe biodiversity as an attribute of three other levels of biological organization: genetic diversity, community diversity, and landscape diversity.

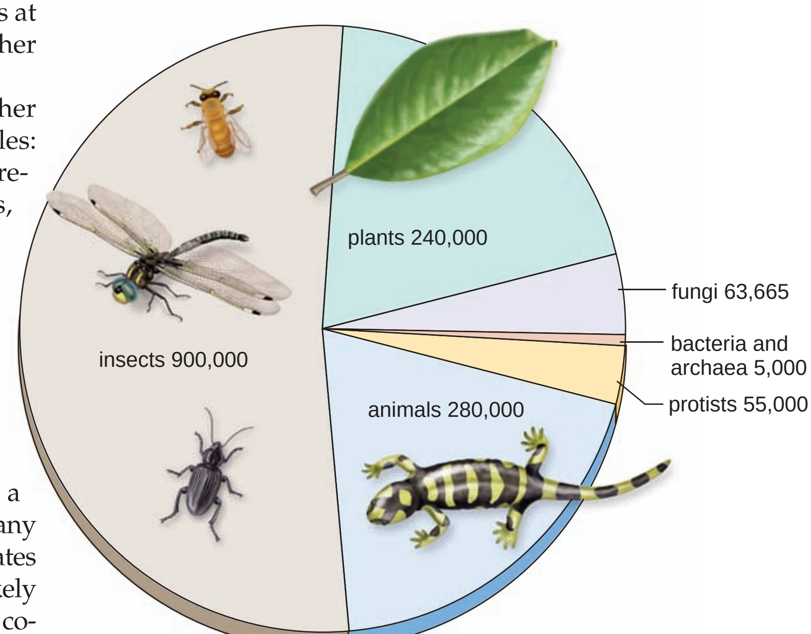


FIGURE 47.1 Number of described species.

There are only about 1.75 million described species; insects are far more prevalent than organisms in other groups. Undescribed species probably number far more than those species that have been described.

Genetic diversity refers to variations among the members of a population. Populations with high genetic diversity are more likely to have some individuals that can survive a change in the structure of their ecosystem. For example, the 1846 potato blight in Ireland, the 1922 wheat failure in the Soviet Union, and the 1984 outbreak of citrus canker in Florida were all made worse by limited genetic variation among these crops. If a species' population is quite small and isolated, it is more likely to eventually become extinct because of a loss of genetic diversity. As organisms become endangered and threatened, they lose their genetic diversity.

Ecosystem diversity is dependent on the interactions of species at a particular locale. One community's species composition can be completely different from that of other communities. Community composition, therefore, increases the levels of biodiversity in the biosphere. Although past conservation efforts frequently concentrated on saving particular charismatic species, such as the California condor, the black-footed ferret, or the spotted owl, this is a weak, shortsighted approach. A more effective approach is to conserve species that have a critical role to play in an ecosystem. Saving an entire community can save many species, and the contrary is also true—disrupting a community threatens the existence of more than one species. Opossum shrimp, *Mysis relicta,* were introduced into Flathead Lake in Montana and its tributaries as food for salmon. The shrimp ate so much zooplankton that there was in the end far less food for the fish and ultimately for the grizzly bears and bald eagles as well (Fig. 47.2).

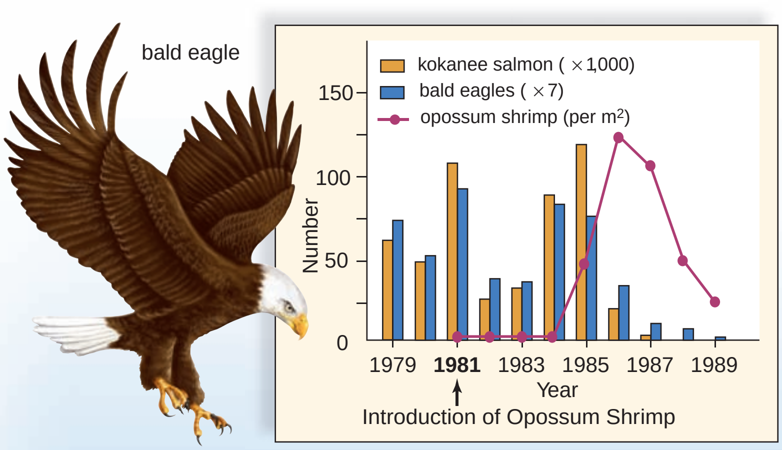
Landscape diversity involves a group of interacting ecosystems; within one **landscape,** for example, there may be plains, mountains, and rivers. Any of these ecosystems can be so fragmented that they are connected by only patches (remnants) or strips of land that allow organisms to move from one ecosystem to the other. Fragmentation of the landscape reduces reproductive capacity and food availability and can disrupt seasonal behaviors.

Distribution of Biodiversity

Biodiversity is not evenly distributed throughout the biosphere; therefore, protecting some areas will save more species than protecting other areas. Biodiversity is highest at the tropics, and it declines toward each pole on land, in fresh water, and in the ocean. Also, more species are found in the coral reefs of the Indonesian archipelago than in other coral reefs as one moves westward across the Pacific.

Some regions of the world are called **biodiversity hotspots** because they contain unusually large concentrations of species. Biodiversity in these hotspots account for about 44% of all known higher plant species and 35% of all terrestrial vertebrate species but cover only about half of 1.4% of the Earth's land area. The island of Madagascar, the Cape region of South Africa, Indonesia, the coast of California, and the Great Barrier Reef of Australia are all biodiversity hotspots.

One surprise of late has been the discovery that rain forest canopies and the deep-sea benthos have many more species than formerly thought. Some conservationists refer to these two areas as biodiversity frontiers.



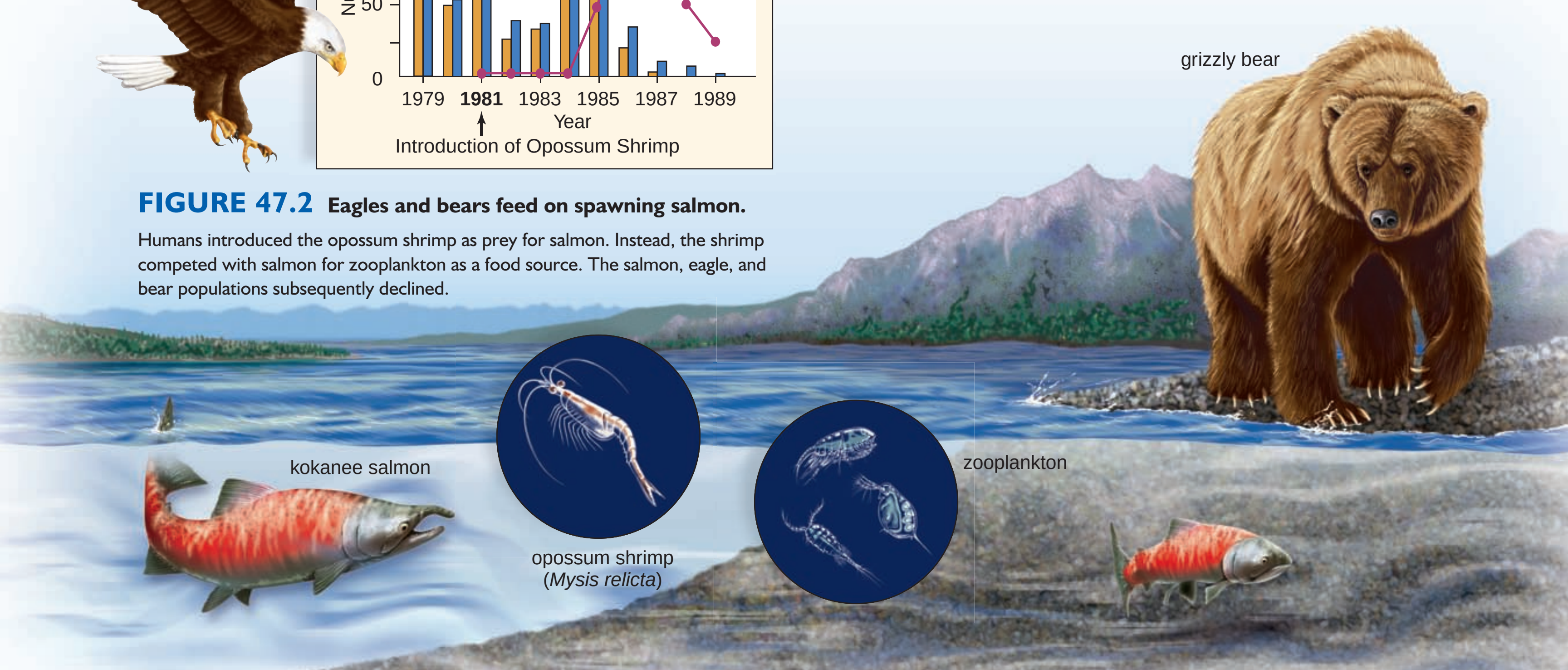


FIGURE 47.2 Eagles and bears feed on spawning salmon.

Humans introduced the opossum shrimp as prey for salmon. Instead, the shrimp competed with salmon for zooplankton as a food source. The salmon, eagle, and bear populations subsequently declined.

Check Your Progress 47.1

1. What is conservation biology?
2. What is biodiversity?

47.2 Value of Biodiversity

Conservation biology strives to reverse the trend toward the possible extinction of living species. To bring this about, it is necessary to make all people aware that biodiversity is a resource of immense value.

Direct Value

Various individual species perform services for human beings and contribute greatly to the value we should place on biodiversity. Only some of the most obvious values are discussed here and illustrated in Figure 47.3.

Medicinal Value

Most of the prescription drugs used in the United States, valued at over $200 billion, were originally derived from living organisms. The rosy periwinkle from Madagascar is an excellent example of a tropical plant that has provided us with useful medicines. Potent chemicals from this plant are now used to treat two forms of cancer: leukemia and Hodgkin disease. Because of these drugs, the survival rate for childhood leukemia has gone from 10% to 90%, and Hodgkin disease is usually curable. Although the value of saving a life cannot be calculated, it is still sometimes easier for us to appreciate the worth of a resource if it is explained in monetary terms. Thus, researchers tell us that, judging from the success rate in the past, an additional 328 types of drugs are yet to be found in tropical rain forests, and the value of this resource to society is probably $147 billion.

You may already know that the antibiotic penicillin is derived from a fungus and that certain species of bacteria produce the antibiotics tetracycline and streptomycin. These drugs have proven to be indispensable in the treatment of diseases, including certain sexually transmitted diseases.

Leprosy is among those diseases for which there is as yet no cure. The bacterium that causes leprosy will not grow in the laboratory, but scientists discovered that it grows naturally in the nine-banded armadillo. Having a source for the bacterium may make it possible to find a cure for leprosy. The blood of horseshoe crabs, *Limulus*, contains a substance called limulus amoebocyte lysate, which is used to ensure that medical devices such as pacemakers, surgical implants, and prosthetic devices are free of bacteria. Hemolymph (the bloodlike fluid in arthropods) is taken from 250,000 crabs a year, and then they are returned to the sea unharmed.

Agricultural Value

Crops such as wheat, corn, and rice are derived from wild plants that have been modified to be high producers. The same high-yield, genetically similar strains tend to be grown worldwide. When rice crops in Africa were being devastated by a virus, researchers grew wild rice plants from thousands

FIGURE 47.3
Direct value of wildlife.
The direct services of wild species, shown on this page and the next, benefit human beings immensely. It is sometimes possible to calculate the monetary value, which is always surprisingly large.

Wild species, like the rosy periwinkle, *Catharanthus roseus,* are sources of many medicines.

Wild species, like many marine species, provide us with food.

Wild species, like the nine-banded armadillo, *Dasypus novemcinctus,* play a role in medical research.

of seed samples until they found one that contained a gene for resistance to the virus. These wild plants were then used in a breeding program to transfer the gene into high-yield rice plants. If this variety of wild rice had become extinct before it could be discovered, rice cultivation in Africa might have collapsed.

Biological pest controls—natural predators and parasites—are often preferable to using chemical pesticides. When a rice pest called the brown planthopper became resistant through natural selection to pesticides, farmers began to use natural brown planthopper enemies instead. The economic savings were calculated at well over $1 billion. Similarly, cotton growers in Cañete Valley, Peru, found that pesticides were no longer working against the cotton aphid because of the resistance the aphids evolved. Research identified natural predators that are now being used to an ever greater degree by cotton farmers. Again, savings have been enormous.

Most flowering plants are pollinated by animals, such as bees, wasps, butterflies, beetles, birds, and bats. The domesticated honeybee, *Apis mellifera*, pollinates almost $10 billion worth of food crops annually in the United States. The danger of this dependency on a single species is exemplified by mites, which have now wiped out more than 20% of the commercial honeybee population in the United States. Where can we get resistant bees? From the wild, of course. The value of wild pollinators to the U.S. agricultural economy has been calculated at $4.1–$6.7 billion a year.

Consumptive Use Value

Humans have had much success cultivating crops, keeping domesticated animals, growing trees in plantations, and so forth. But so far, aquaculture, the growing of fish and shellfish for human consumption, has contributed only minimally to human welfare—instead, most freshwater and marine harvests depend on the catching of wild animals, such as fishes (e.g., trout, cod, tuna, and flounder), crustaceans (e.g., lobsters, shrimps, and crabs), and mammals (e.g., whales). Obviously, these aquatic organisms are an invaluable biodiversity resource.

The environment provides a variety of other products that are sold in the marketplace worldwide, including wild fruits and vegetables, skins, fibers, beeswax, and seaweed. Also, by hunting and fishing, some people obtain their meat directly from the environment. In one study, researchers calculated that the economic value of wild pig in the diet of native hunters in Sarawak, East Malaysia, was approximately $40 million per year.

Similarly, many trees are still felled in the natural environment for their wood. Researchers have calculated that a species-rich forest in the Peruvian Amazon is worth far more if the forest is used for fruit and rubber production than for timber production. Fruit and the latex needed to produce rubber can be brought to market for an unlimited number of years, whereas once the trees are gone, no more timber can be harvested.

Wild species, like the lesser long-nosed bat, *Leptonycteris curasoae*, are pollinators of agricultural and other plants.

Wild species, like ladybugs, *Coccinella*, play a role in biological control of agricultural pests.

Wild species, like rubber trees, *Hevea*, can provide a product indefinitely if the forest is not destroyed.

Indirect Value

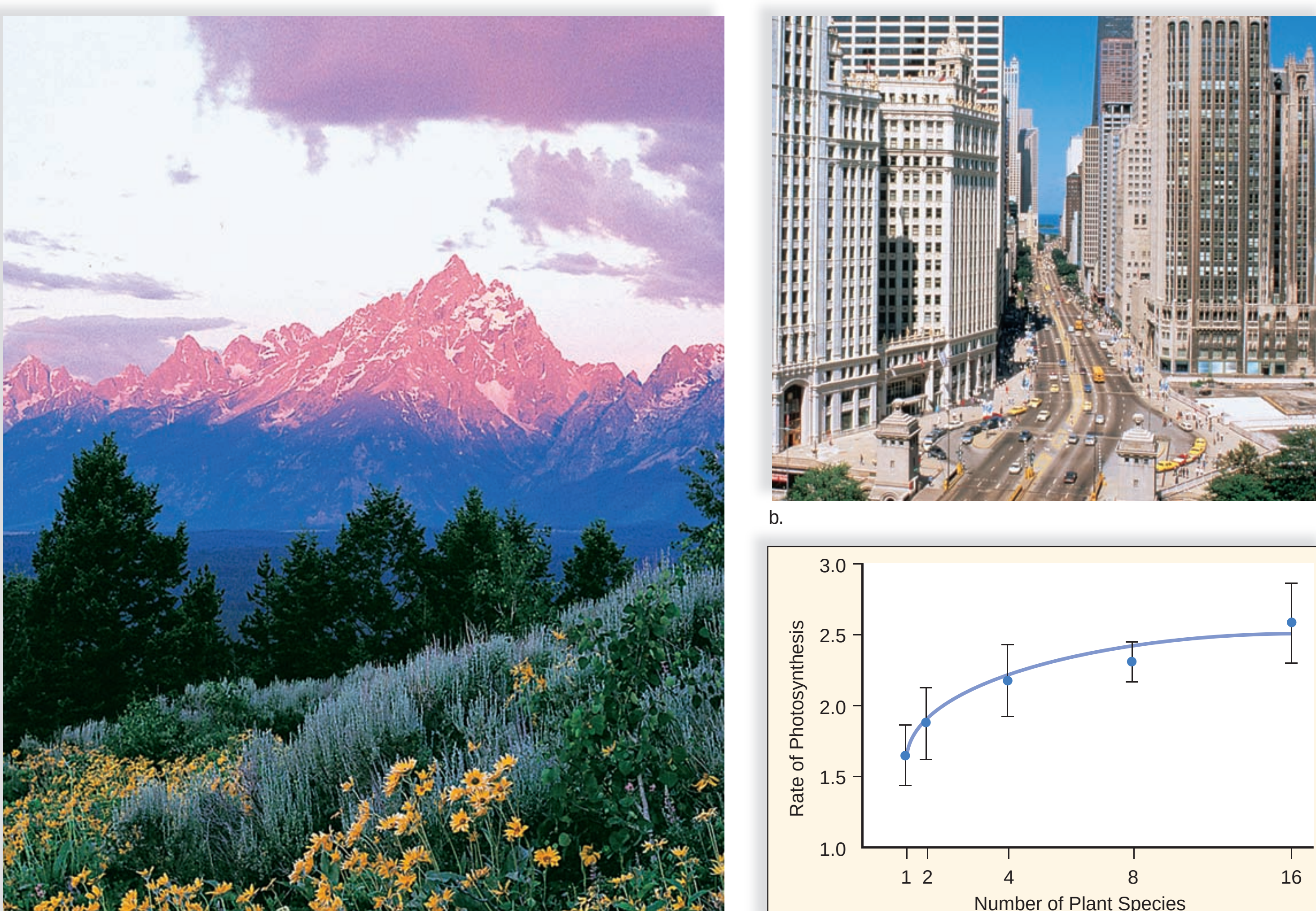
The wild species we have been discussing play a role in their respective ecosystems. If we want to preserve them, it is more economical to save the ecosystems, and subsequently all the species within, than individual species. Ecosystems perform many services for modern humans, who increasingly live in cities. Humans evolved outdoors and today, we still have the innate need to "get away" from our indoor lifestyles. It is thought that the function of houseplants is "bringing the outdoors and its biodiversity inside" since that is what we require, but often do not make the time to fill this need. These services are said to be indirect because they are pervasive and not easily discernible (Fig. 47.4). Even so, our very survival depends on the functions that ecosystems perform for us. Think of the alternative if there was no wild ecosystem to which to escape the rat race.

Biogeochemical Cycles

Ecosystems are characterized by energy flow and chemical cycling. The biodiversity within ecosystems contributes to the workings of the water, carbon, nitrogen, phosphorus, and other biogeochemical cycles. We are dependent on these cycles for fresh water, removal of carbon dioxide from the atmosphere, uptake of excess soil nitrogen, and provision of phosphate. When human activities upset the usual workings of biogeochemical cycles, the environmental consequences include the release of excess pollutants that are harmful to us. Technology is currently unable to artificially contribute to or create any of the biogeochemical cycles.

Waste Disposal

Decomposers break down dead organic matter and other types of wastes to inorganic nutrients that are used by the producers within ecosystems. This function aids humans immensely because we dump millions of tons of waste material into natural ecosystems each year. If it were not for decomposition, waste would soon cover the entire surface of our planet. We can build sewage treatment plants, but they are expensive, and few of them break down solid wastes completely to inorganic nutrients. It



a. c.

FIGURE 47.4 Indirect value of ecosystems.

a. Natural ecosystems provide (**b**) human-impacted ecosystems with many ecological services. **c.** Research results show that the higher the biodiversity (measured by number of plant species), the greater the rate of photosynthesis of an experimental community.

is less expensive and more efficient to provide plants and trees with partially treated wastewater and let soil bacteria cleanse it completely.

Biological communities are also capable of breaking down and immobilizing pollutants, such as heavy metals and pesticides, that humans release into the environment. A review of wetland functions in Canada assigned a value of $50,000 per hectare (100 acres, or 10,000 m^2) per year to the ability of natural areas to purify water and take up pollutants.

Provision of Fresh Water

Few terrestrial organisms are adapted to living in a salty environment—they need fresh water. The water cycle continually supplies fresh water to terrestrial ecosystems. Humans use fresh water in innumerable ways, including drinking it and irrigating their crops. Freshwater ecosystems, such as rivers and lakes, also provide us with fishes and other organisms for food.

Unlike other commodities, there is no substitute for fresh water. We can remove salt from seawater to obtain fresh water, but the cost of desalination is about four to eight times the average cost of fresh water acquired via the water cycle.

Forests and other natural ecosystems exert a "sponge effect." They soak up water and then release it at a regular rate. When rain falls in a natural area, plant foliage and dead leaves lessen its impact, and the soil slowly absorbs it, especially if the soil has been aerated by organisms. The water-holding capacity of forests reduces the possibility of flooding. The value of a marshland outside Boston, Massachusetts, has been estimated at $72,000 per hectare per year solely on its ability to reduce floods. Forests release water slowly for days or weeks after the rains have ceased. Rivers flowing through forests in West Africa release twice as much water halfway through the dry season, and between three and five times as much at the end of the dry season, as do rivers from coffee plantations.

Prevention of Soil Erosion

Intact ecosystems naturally retain soil and prevent soil erosion. The importance of this ecosystem attribute is especially observed following deforestation. In Pakistan, the world's largest dam, the Tarbela Dam, is losing its storage capacity of 12 billion m^3 many years sooner than expected because silt is building up behind the dam due to deforestation. At one time, the Philippines were exporting $100 million worth of oysters, mussels, clams, and cockles each year. Now, silt carried down rivers following deforestation is smothering the mangrove ecosystem that serves as a nursery for the sea. Most coastal ecosystems are not as bountiful as they once were because of deforestation and a myriad of other assaults.

Regulation of Climate

At the local level, trees provide shade and reduce the need for fans and air conditioners during the summer. Proper placement of shade trees near a home can reduce energy bills.

Globally, forests restore the climate because they take up carbon dioxide. The leaves of trees use carbon dioxide when they photosynthesize, the bodies of the trees store carbon, and oxygen is released as a by-product. When trees are cut and burned, carbon dioxide is released into the atmosphere. The reduction in forests reduces the carbon dioxide uptake and the oxygen output. This change in the atmospheric gases, especially greenhouse gases such as CO_2, affects the amount of solar radiation retained on Earth's surface. Large scale deforestation may affect the global atmosphere and, in turn, the climate.

Ecotourism

Almost everyone prefers to vacation in the natural beauty of an ecosystem. In the United States, nearly 100 million people enjoy vacationing in a natural setting. To do so, they spend $4 billion each year on fees, travel, lodging, and food. Many tourists want to go sport fishing, whale watching, boat riding, hiking, birdwatching, and the like. Others want to merely immerse themselves in the beauty and serenity of a natural environment. Many underdeveloped countries in tropical regions are taking advantage of this by offering "ecotours" of the local biodiversity. Providing guided tours of forests is often more profitable than destroying them.

Biodiversity and Natural Ecosystems

Massive changes in biodiversity, such as deforestation, have a significant impact on ecosystems. Researchers are interested in determining whether a high degree of biodiversity also helps ecosystems function more efficiently. To test the benefits of biodiversity in a Minnesota grassland habitat, researchers sowed plots with seven levels of plant diversity. Their study found that ecosystem performance improves with increasing diversity. A similar study in California also showed greater overall resource use in more diverse plots because of resource partitioning among the plants.

Another group of experimenters tested the effects of an increase in diversity at four levels: producers, herbivores, parasites, and decomposers. They found that the rate of photosynthesis increased as diversity increased (Fig. 47.4*c*). A computer simulation has shown that the response of a deciduous forest to elevated carbon dioxide is a function of species diversity. The more complex community, composed of nine tree species, exhibited a 30% greater amount of photosynthesis than a community composed of a single species.

More studies are needed to test whether biodiversity maximizes resource acquisition and retention within an ecosystem. Also, are more diverse ecosystems better able to withstand environmental changes and invasions by other species, including pathogens? Then, too, how does fragmentation affect the distribution of organisms within an ecosystem and the functioning of an ecosystem?

Check Your Progress 47.2

1. Explain the difference between a direct value of biodiversity and an indirect value of biodiversity.

47.3 Causes of Extinction

To stem the tide of extinction due to human activities, it is first necessary to identify its causes. Researchers examined the records of 1,880 threatened and endangered wild species in the United States and found that habitat loss was involved in 85% of the cases (Fig. 47.5*a*). Exotic species had a hand in nearly 50%, pollution was a factor in 24%, overexploitation in 17%, and disease in 3%. The percentages add up to more than 100% because most of these species are imperiled for more than one reason. Macaws are a good example that a combination of factors can lead to a species decline (Fig. 47.5*b*). Not only has their habitat been reduced by encroaching timber and mining companies, but macaws are also hunted for food and collected for the pet trade.

Habitat Loss

Habitat loss has occurred in all ecosystems, but concern has now centered on tropical rain forests and coral reefs because they are particularly rich in species. A sequence of events in Brazil offers a fairly typical example of the manner in which rain forest is converted to land uninhabitable for wildlife. The construction of a major highway into the forest first provided a way to reach the interior of the forest (see Fig. 47.5*b*). Small towns and industries sprang up along the highway, and roads branching off the main highway gave rise to even more roads. The result was fragmentation of the once immense forest. The government offered subsidies to anyone willing to take up residence in the forest, and the people who came cut and burned trees in patches (see Fig. 47.5*b*). Tropical soils contain limited nutrients, but when the trees are burned, nutrients are released that support a lush growth for the grazing of cattle for about three years. However, once the land was degraded (see Fig. 47.5*b*), the farmers moved on to another portion of the forest to start over again.

Loss of habitat also affects freshwater and marine biodiversity. Coastal degradation is mainly due to the large concentration of people living on or near the coast. Already, 60% of coral reefs have been destroyed or are on the verge of destruction; it is possible that all coral reefs may disappear during the next 40 years unless our behaviors drastically change. Mangrove forest destruction is also a problem; Indonesia, with the most mangrove acreage, has lost 45% of its mangroves, and the percentage is even higher for other tropical countries. Wetland areas, estuaries, and seagrass beds are also being rapidly destroyed by the actions of humans.

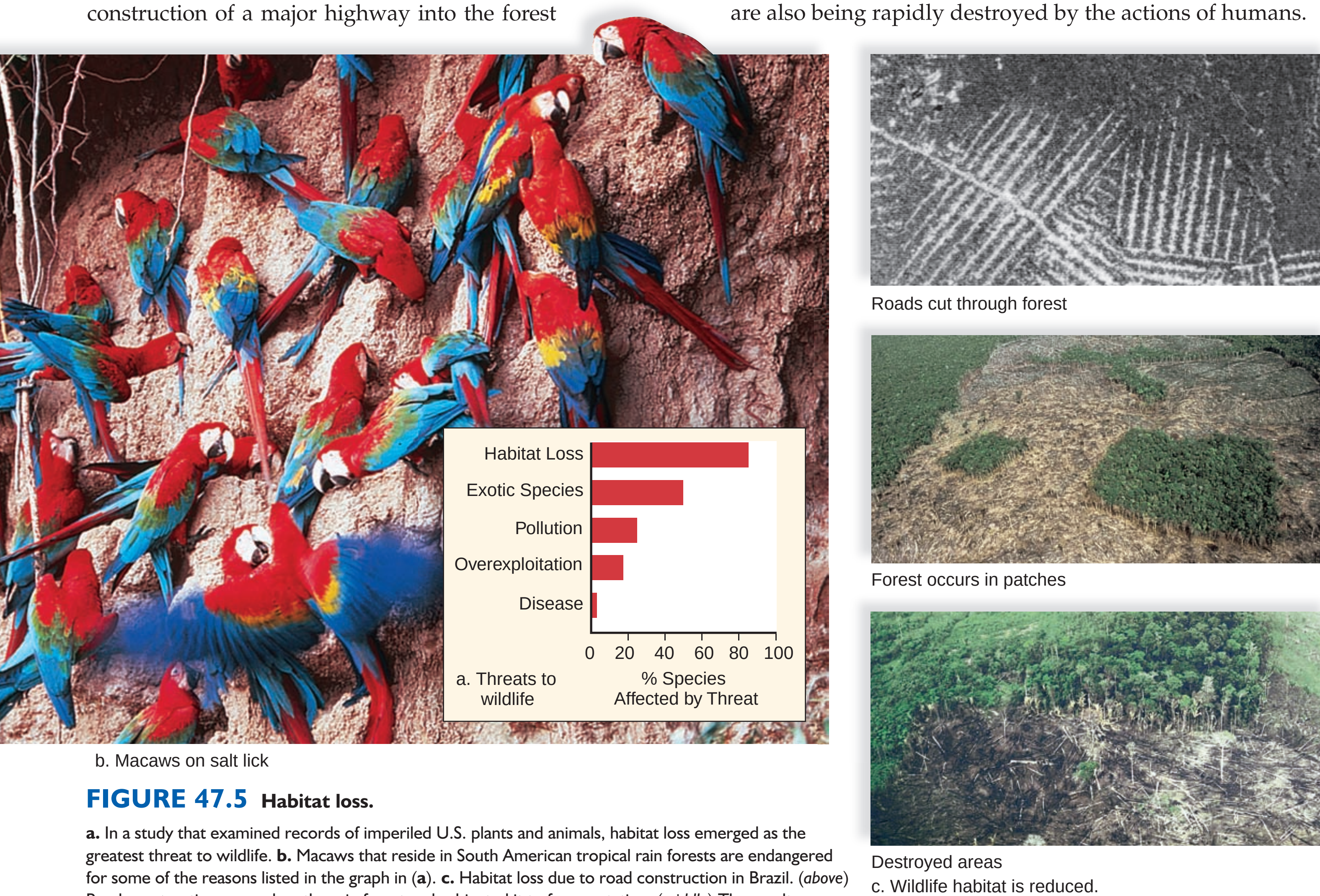


FIGURE 47.5 Habitat loss.

a. In a study that examined records of imperiled U.S. plants and animals, habitat loss emerged as the greatest threat to wildlife. **b.** Macaws that reside in South American tropical rain forests are endangered for some of the reasons listed in the graph in (**a**). **c.** Habitat loss due to road construction in Brazil. (*above*) Road construction opened up the rain forest and subjected it to fragmentation. (*middle*) The result was patches of forest and degraded land. (*below*) Wildlife could not live in destroyed portions of the forest.

Exotic Species

Exotic species, sometimes called alien species, are nonnative members of an ecosystem. Ecosystems around the globe are characterized by unique assemblages of organisms that have evolved together in one location. Migrating to a new location is not usually possible because of barriers such as oceans, deserts, mountains, and rivers. Humans, however, have introduced exotic species into new ecosystems in the following ways:

Colonization Europeans, in particular, brought various familiar species with them when they colonized new places. For example, the pilgrims brought the dandelion to the United States as a familiar salad green. In addition, they introduced pigs to North America that have since become feral, reverting to their wild state. In some parts of the United States, feral pigs are very destructive.

Horticulture and agriculture Some exotics now taking over vast tracts of land have escaped from cultivated areas. Kudzu is a vine from Japan that the U.S. Department of Agriculture thought would help prevent soil erosion. The plant now covers much landscape in the South, including even walnut, magnolia, and sweet gum trees (Fig. 47.6*a*). The water hyacinth was introduced to the United States from South America because of its beautiful flowers. Today, it clogs up waterways and diminishes natural diversity.

Accidental transport Global trade and travel accidentally bring many new species from one country to another. Researchers found that the ballast water released from ships into Coos Bay, Oregon, contained 367 marine species from Japan. The zebra mussel from the Caspian Sea was accidentally introduced into the Great Lakes in 1988. It now forms dense beds that squeeze out native mussels. Other organisms accidentally introduced into the United States include the Formosan termite, the Argentinian fire ant, and the nutria, a type of large rodent.

Exotic species can disrupt food webs. As mentioned earlier, opossum shrimp introduced into a lake in Montana added a trophic level that in the end meant less food for bald eagles and grizzly bears (see Fig. 47.2).

Exotics on Islands

Islands are particularly susceptible to environmental discord caused by the introduction of exotic species. Islands have unique assemblages of native species that are closely adapted to one another and cannot compete well against exotics. Myrtle trees, *Myrica faya,* introduced into the Hawaiian Islands from the Canary Islands, are symbiotic with a type of bacterium that is capable of nitrogen fixation. This feature allows the species to establish itself on nutrient-poor volcanic soil, a distinct advantage in Hawaii. Once established, myrtle trees call a halt to the normal succession of native plants on volcanic soil.

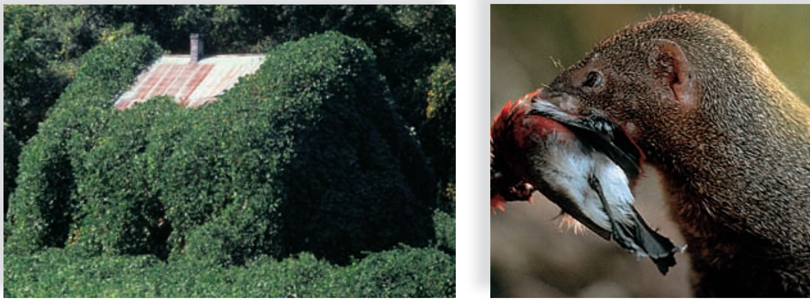
The brown tree snake has been introduced onto a number of islands in the Pacific Ocean. The snake eats adult birds, their eggs, and nestlings. On Guam, it has reduced ten native bird species to the point of extinction. On the Galápagos Islands, black rats have reduced populations of giant tortoise, while goats and feral pigs have changed the vegetation from highland forest to pampaslike grasslands and destroyed stands of cacti. In Australia, mice and rabbits have stressed native marsupial populations. Mongooses introduced into the Hawaiian Islands to control rats also prey on native birds (Fig. 47.6*b*).

Pollution

In the present context, **pollution** can be defined as any environmental change that adversely affects the lives and health of living things. Pollution has been identified as the third main cause of extinction. Pollution can also weaken organisms and lead to disease, the fifth main cause of extinction. Biodiversity is particularly threatened by the following types of environmental pollution:

Acid deposition Both sulfur dioxide from power plants and nitrogen oxides in automobile exhaust are converted to acids when they combine with water vapor in the atmosphere. These acids return to Earth as either wet deposition (acid rain or snow) or dry deposition (sulfate and nitrate salts). Sulfur dioxide and nitrogen oxides are emitted in one locale, but deposition occurs across state and national boundaries. Acid deposition causes trees to weaken and increases their susceptibility to disease and insects. It also kills small invertebrates and decomposers so that the entire ecosystem is threatened. Many lakes in the northern United States are now lifeless because of the effects of acid deposition.

Eutrophication Lakes are also under stress due to overenrichment. When lakes receive excess nutrients due to runoff from agricultural fields and wastewater from sewage treatment, algae begin to grow in



a. b.

FIGURE 47.6 Exotic species.

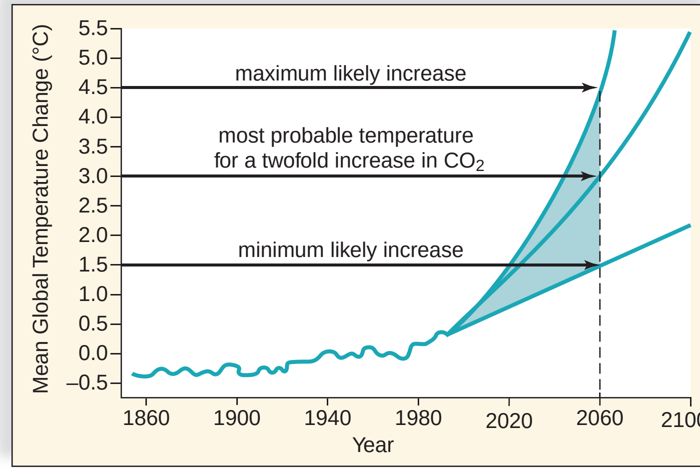
a. Kudzu, a vine from Japan, was introduced in several southern states to control erosion. Today, kudzu has taken over and displaced many native plants.
b. Mongooses were introduced into Hawaii to control rats, but they also prey on native birds.

abundance. An algal bloom is apparent as a green scum or excessive mats of filamentous algae. Upon death, the decomposers break down the algae, but in so doing, they use up oxygen. A decreased amount of oxygen is available to fish, leading sometimes to a massive fish kill.

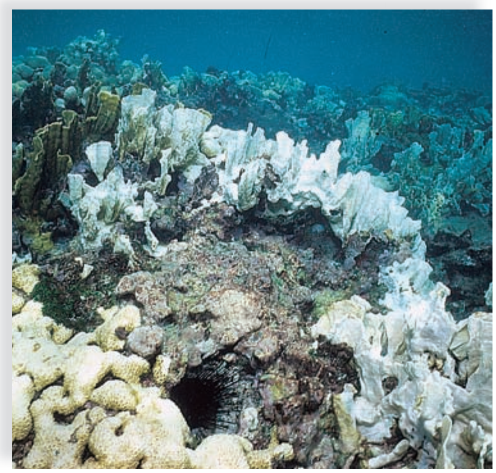
Ozone depletion The ozone shield is a layer of ozone (O_3) in the stratosphere, some 50 km above the Earth. The ozone shield absorbs most of the wavelengths of harmful ultraviolet (UV) radiation so that they do not strike the Earth. The cause of ozone depletion can be traced to chlorine atoms (Cl^-) that come from the breakdown of chlorofluorocarbons (CFCs). The best-known CFC is Freon, a heat transfer agent still found in refrigerators and air conditioners today. Severe ozone shield depletion can impair crop and tree growth and also kill plankton (microscopic plant and animal life) that sustain oceanic life. The immune system and the ability of all organisms to resist infectious diseases will most likely be weakened.

Organic chemicals Our modern society uses organic chemicals in all sorts of ways. Organic chemicals called nonylphenols are used in products ranging from pesticides to dishwashing detergents, cosmetics, plastics, and spermicides. These chemicals mimic the effects of hormones, and in that way most likely harm wildlife. Salmon are born in fresh water but mature in salt water. After investigators exposed young fish to nonylphenol, they found that 20–30% were unable to make the transition between fresh and salt water. Nonylphenols cause the pituitary to produce prolactin, a hormone that may prevent saltwater adaptation.

Global warming The expression **global warming** refers to an expected increase in average temperature during the twenty-first century. You may recall from Chapter 46 that carbon dioxide is a gas that comes from the burning of fossil fuels, and methane is a gas that comes from oil and gas wells, rice paddies, and animals. These gases are known as greenhouse gases because, just like the panes of a greenhouse, they allow solar radiation to pass through but hinder the escape of its heat back into space. Data collected around the world show a steady rise in CO_2 concentration. These data are used to generate computer models that predict the Earth may warm to temperatures higher than currently experienced (Fig. 47.7*a*). An upward shift in temperatures could influence everything from growing seasons in plants to migratory patterns in animals.



a.



b.

FIGURE 47.7 Global warming.

a. Mean global temperature is expected to rise due to the introduction of greenhouse gases into the atmosphere. **b.** Global warming has the potential to significantly affect the world's biodiversity distribution. A temperature rise of only a few degrees causes coral reefs to "bleach" and become lifeless. If, in the meantime, migration occurs, coral reefs could move northward.

As temperatures rise, regions of suitable climate for various terrestrial species may shift toward the poles and higher elevations. Extinctions are expected because the present assemblages of species in ecosystems will be disrupted as some species migrate northward, leaving others behind. Plants migrate when seeds disperse, and growth occurs in a new locale. For example, to remain in a favorable habitat, it's been calculated that the rate of beech tree migration would have to be 40 times faster than has ever been observed. It seems unlikely that beech or any other type of tree would be able to meet the pace required. Then, too, many species of organisms are confined to relatively small habitat patches that are surrounded by agricultural or urban areas they would not be able to cross. And even if they have the capacity to disperse to new sites, suitable habitats may not be available. If the global climate changes faster than organisms can migrate, extinction of such species is likely. Other species may experience population increase. For example, parasites and pests that are usually killed by cold winters will now be able to survive in greater numbers. The tropics may very well expand, and whether present-day temperate-zone agriculture will survive is questionable.