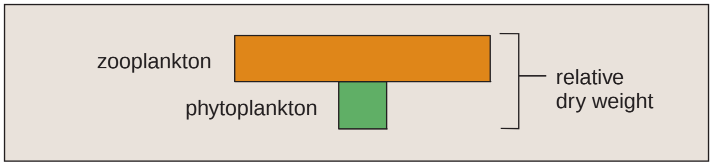
pyramids, which have more herbivores than producers, are called inverted pyramids:



These kinds of problems are making some ecologists hesitant about using pyramids to describe ecological relationships. One more problem is what to do with the decomposers, which are rarely included in pyramids, even though a large portion of energy becomes detritus in many ecosystems.

Chemical Cycling

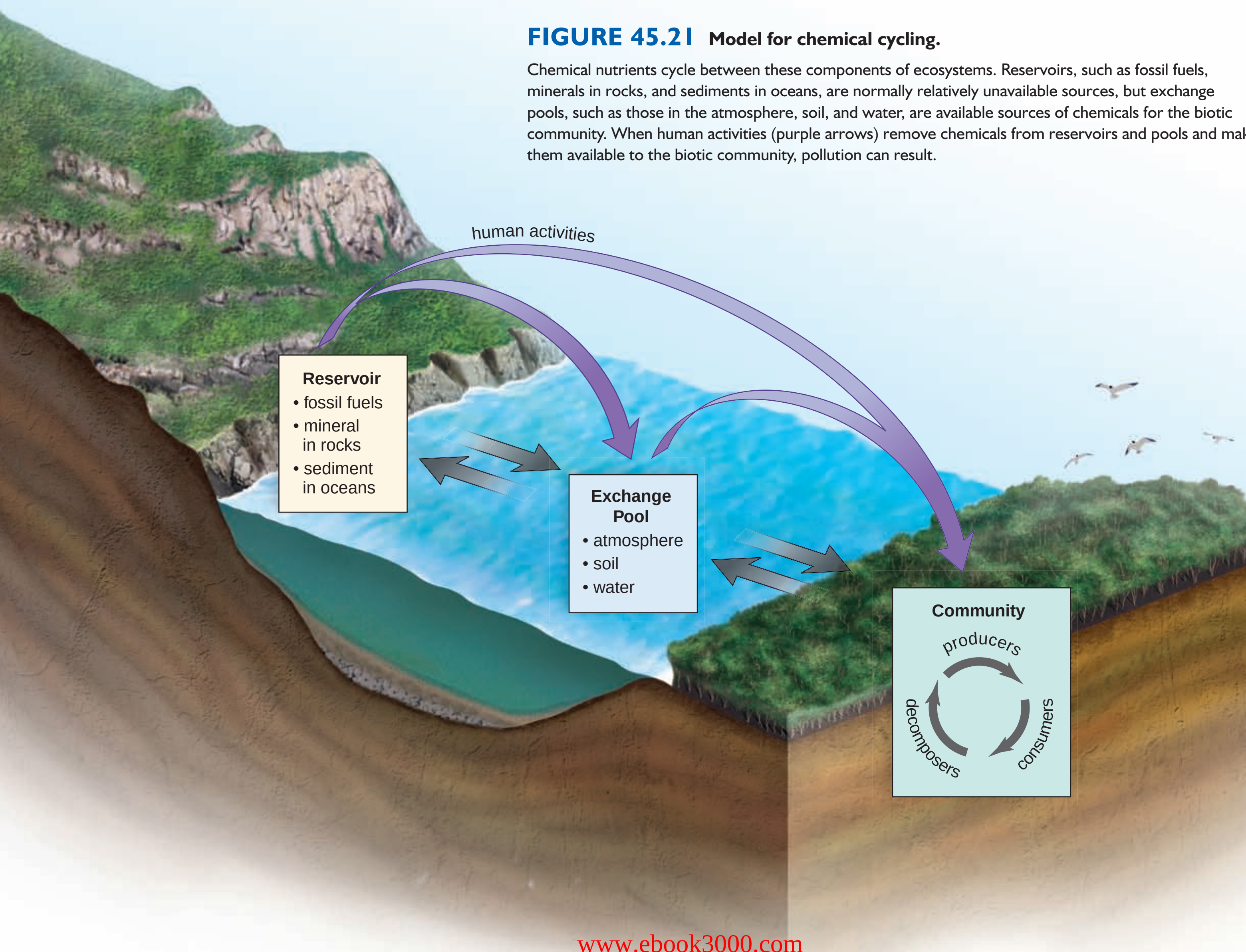
The pathways by which chemicals circulate through ecosystems involve both living (biotic) and nonliving (geologic) components; therefore, they are known as **biogeochemical cycles.** In this chapter, we describe four of the biogeochemical cycles: the water, carbon, phosphorus, and nitrogen cycles. A biogeochemical cycle may be sedimentary or gaseous. The phosphorus cycle is a sedimentary cycle; the chemical is absorbed from the soil by plant roots, passed to heterotrophs, and eventually returned to the soil by decomposers. The carbon and nitrogen cycles are gaseous, meaning that the chemical returns to and is withdrawn from the atmosphere as a gas.

Chemical cycling involves the components of ecosystems shown in Figure 45.21. A *reservoir* is a source normally unavailable to producers, such as the carbon present in calcium carbonate shells on ocean bottoms. An *exchange pool* is a source from which organisms do generally take chemicals, such as the atmosphere or soil. Chemicals move along food chains in a *biotic community*, perhaps never entering an exchange pool.

Human activities (purple arrows) remove chemicals from reservoirs and exchange pools and make them available to the biotic community. In this way, human activities result in pollution because they upset the normal balance of nutrients for producers in the environment.

FIGURE 45.21 Model for chemical cycling.

Chemical nutrients cycle between these components of ecosystems. Reservoirs, such as fossil fuels, minerals in rocks, and sediments in oceans, are normally relatively unavailable sources, but exchange pools, such as those in the atmosphere, soil, and water, are available sources of chemicals for the biotic community. When human activities (purple arrows) remove chemicals from reservoirs and pools and make them available to the biotic community, pollution can result.



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The Water Cycle

The **water (hydrologic) cycle** is described in Figure 45.22. A **transfer rate** is defined as the amount of a substance that moves from one component of the environment to another within a specified period of time. The width of the arrows in Figure 45.22 indicates the transfer rate of water.

During the water cycle, fresh water is first distilled from salt water through evaporation. During evaporation, a liquid, in this case water, changes to a gaseous state. The sun's rays cause fresh water to evaporate from the seawater, and the salts are left behind. Next, condensation occurs. During condensation, a gas is converted into a liquid. For example, vaporized fresh water rises into the atmosphere, is stored in clouds, cools, and falls as rain over the oceans and the land.

Water evaporates from land and from plants (evaporation from plants is called transpiration) and also from bodies of fresh water. Because land lies above sea level, gravity eventually returns all fresh water to the sea. In the meantime, water is contained within standing waters (lakes and ponds), flowing water (streams and rivers), and groundwater.

Some of the water from precipitation (e.g., rain, snow, sleet, hail, and fog) 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. Because water infiltrates through the soil and rock layers, sometimes groundwater is also located in aquifers, rock layers that contain water and release it in appreciable quantities to wells or springs. Aquifers are recharged when rainfall and melted snow percolate into the soil.

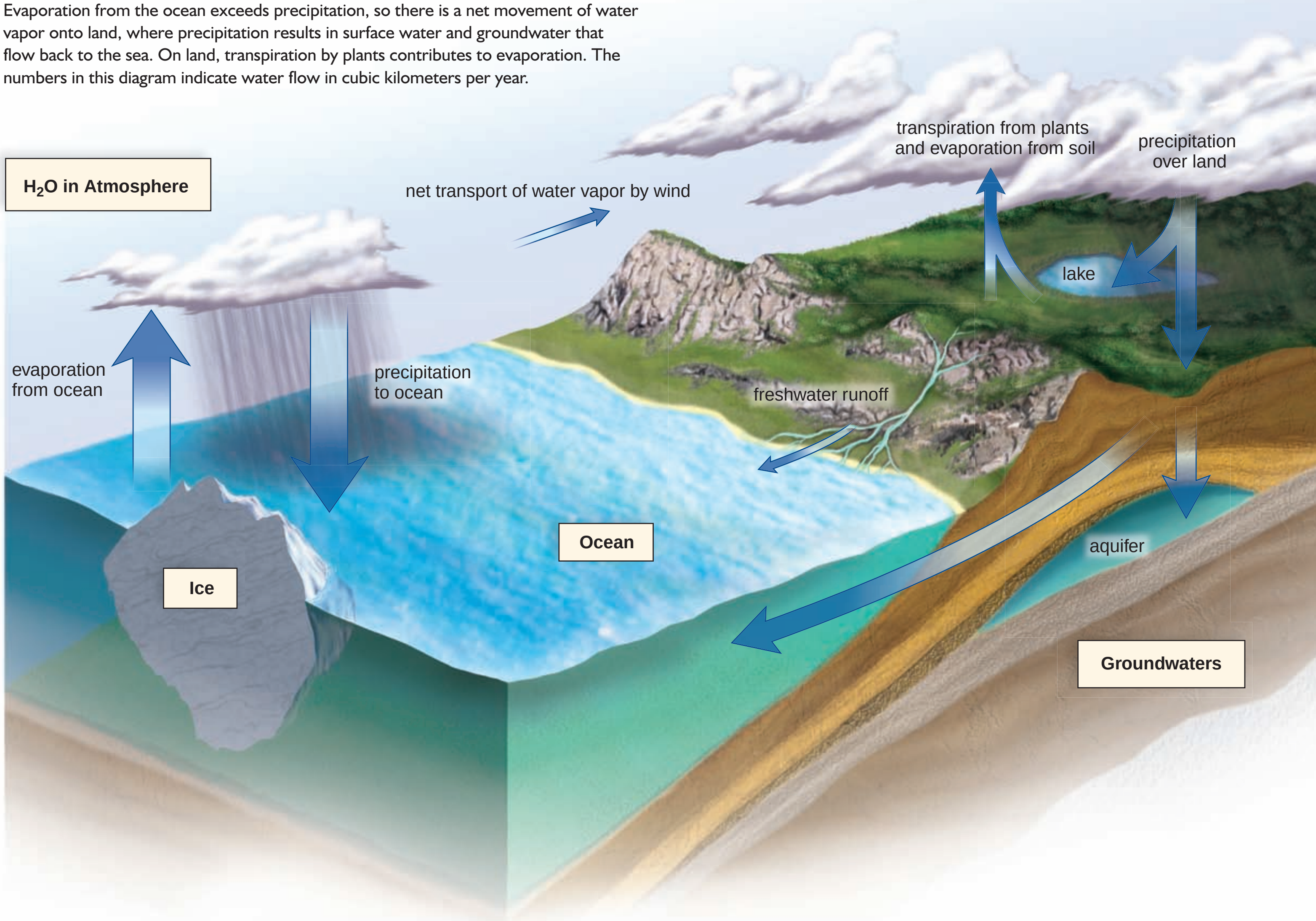
Human Activities

In some parts of the United States, especially the arid West and southern Florida, withdrawals from aquifers exceed any possibility of recharge. This is called "groundwater mining." In these locations, the groundwater is dropping, and residents may run out of groundwater, at least for irrigation purposes, within a few years.

Fresh water, which makes up only about 3% of the world's supply of water, is called a renewable resource because a new supply is always being produced because of the water cycle. But it is possible to run out of fresh water when the available supply is not adequate or is polluted so that it is not usable.

FIGURE 45.22 The hydrologic (water) cycle.

Evaporation from the ocean exceeds precipitation, so there is a net movement of water vapor onto land, where precipitation results in surface water and groundwater that flow back to the sea. On land, transpiration by plants contributes to evaporation. The numbers in this diagram indicate water flow in cubic kilometers per year.



The Carbon Cycle

In the carbon cycle, organisms in both terrestrial and aquatic ecosystems exchange carbon dioxide (CO_2) with the atmosphere (Fig. 45.23). Therefore, the CO_2 in the atmosphere is the exchange pool for the carbon cycle. On land, plants take up CO_2 from the air and, through photosynthesis, they incorporate carbon into nutrients that are used by autotrophs and heterotrophs alike. **1** When organisms, including plants, respire, carbon is returned to the atmosphere as CO_2. **2** CO_2 then recycles to plants by way of the atmosphere.

In aquatic ecosystems, the exchange of CO_2 with the atmosphere is indirect. **3** Carbon dioxide from the air combines with water to produce bicarbonate ion (HCO_3^-), a source of carbon for algae that produce food for themselves and for heterotrophs. Similarly, when aquatic organisms respire, the CO_2 they give off becomes HCO_3^-. **4** The amount of bicarbonate in the water is in equilibrium with the amount of CO_2 in the air.

Reservoirs Hold Carbon

Living and dead organisms contain organic carbon and serve as one of the reservoirs for the carbon cycle. The world's biotic components, particularly trees, contain 800 billion tons of organic carbon, and an additional 1,000–3,000 billion metric tons are estimated to be held in the remains of plants and animals in the soil. **5** Ordinarily, decomposition of organisms returns CO_2 to the atmosphere.

Some 300 MYA, plant and animal remains were transformed into coal, oil, and natural gas, the materials we call fossil fuels. Another reservoir for carbon is the inorganic carbonate that accumulates in limestone and in calcium carbonate shells. Many marine organisms have calcium carbonate shells that remain in bottom sediments long after the organisms have died. Geologic forces change these sediments into limestone.

Human Activities and the Carbon Cycle

6 More CO_2 is being deposited in the atmosphere than is being removed, largely due to the burning of fossil fuels and the destruction of forests to make way for farmland and pasture. When we humans do away with forests, we reduce a reservoir and also the very organisms that take up excess carbon dioxide. Today, the amount of CO_2 released into the atmosphere is about twice the amount that remains in the atmosphere. Much of the CO_2 dissolves into the ocean.

Other gases, as well as CO_2, are excess, emitted into the atmosphere due to human activities. The other gases include nitrous oxide (N_2O) from fertilizers and animal wastes and methane (CH_4) from bacterial decomposition that takes place particularly in the guts of animals, in sediments, and in flooded rice paddies. These gases are known

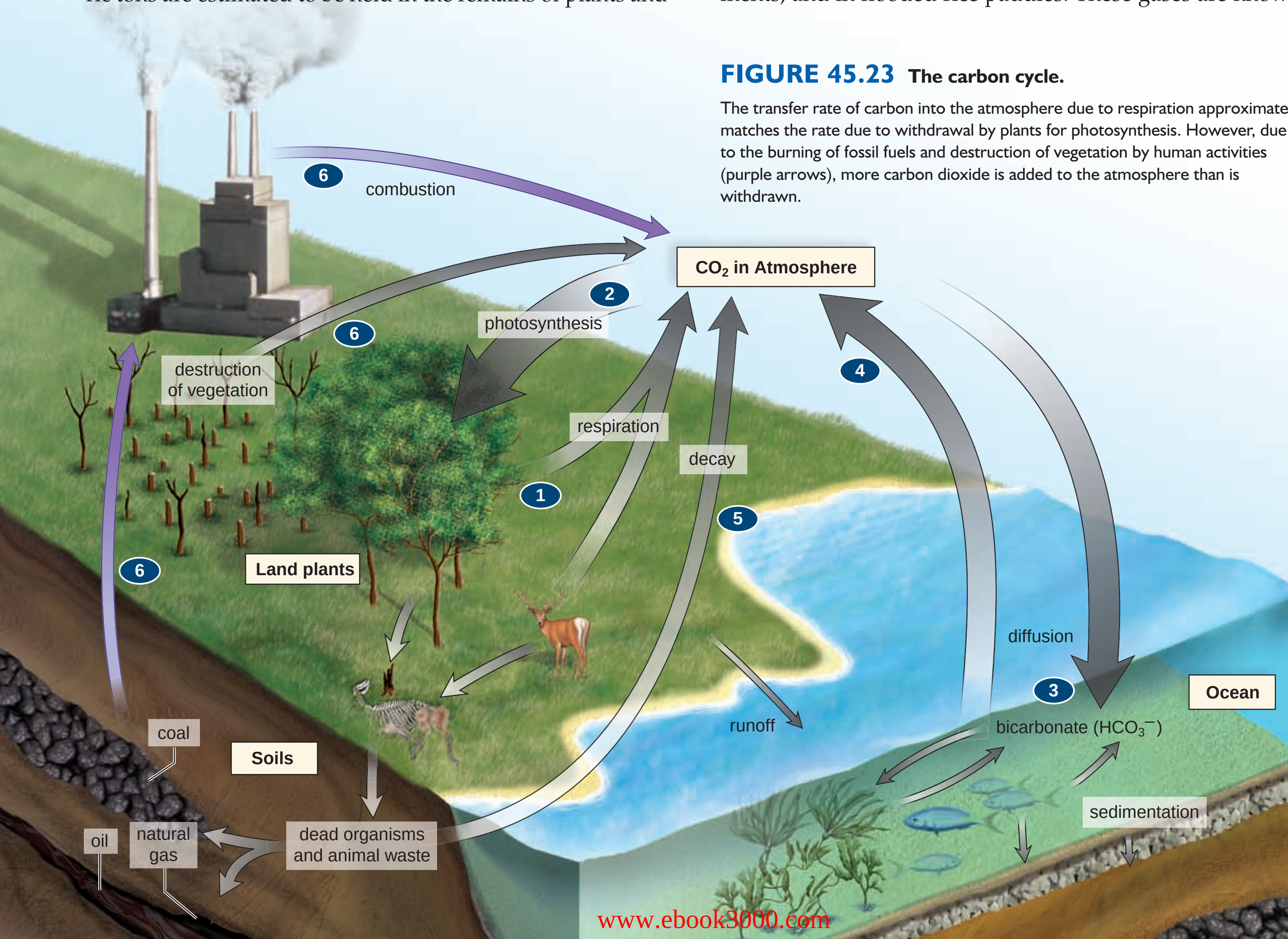


FIGURE 45.23 **The carbon cycle.**

The transfer rate of carbon into the atmosphere due to respiration approximately matches the rate due to withdrawal by plants for photosynthesis. However, due to the burning of fossil fuels and destruction of vegetation by human activities (purple arrows), more carbon dioxide is added to the atmosphere than is withdrawn.

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as **greenhouse gases** because, just like the panes of a greenhouse, they allow solar radiation to pass through but hinder the escape of infrared rays (heat) back into space. This phenomenon has come to be known as the **greenhouse effect.** The greenhouse gases are contributing significantly to an overall rise in the Earth's ambient temperature, a trend called **global warming.** The global climate has already warmed about 0.6°C since the Industrial Revolution. Computer models are unable to consider all possible variables, but the Earth's temperature may rise 1.5–4.5°C by 2100 if greenhouse emissions continue at the current rates.

It is predicted that, as the oceans warm, temperatures in the polar regions will rise to a greater degree than in other regions. If so, glaciers will melt, and sea level will rise, not only due to this melting but also because water expands as it warms. Increased rainfall is likely along the coasts, while dryer conditions are expected inland. Coastal agricultural lands, such as the deltas of Bangladesh and China, will be inundated with seawater, and billions of dollars will have to be spent to keep coastal cities such as New Orleans, New York, Boston, Miami, and Galveston from disappearing into the sea.

The Phosphorus Cycle

Figure 45.24 depicts the phosphorus cycle. (1) Phosphorus, trapped in oceanic sediments, moves onto land due to a geologic uplift. (2) On land, the very slow weathering of rocks places (3) phosphate ions (PO_3^- and HPO_4^+) in the soil. (4) Some of these become available to plants, which use phosphate in a variety of molecules, including phospholipids, ATP, and the nucleotides that become a part of DNA and RNA. (5) Animals eat producers and incorporate some of the phosphate into their teeth, bones, and shells, which take many years to decompose. (6) However, eventually the death and decay of all organisms and also the decomposition of animal wastes make phosphate ions available to producers once again. Because the available amount of phosphate is already being used within food chains, phosphate is usually a limiting inorganic nutrient for plants—that is, the lack of it limits the size of populations in ecosystems.

(7) Some phosphate naturally runs off into aquatic ecosystems, where algae acquire phosphate from the water before it becomes trapped in sediments. Phosphate in marine sediments does not become available to producers on land again until a geologic upheaval exposes sedimentary rocks on land. Now, the cycle begins again.

Human Activities and the Phosphorus Cycle

(8) Human beings boost the supply of phosphate by mining phosphate ores for producing fertilizer and detergents. Runoff of phosphate and nitrogen due to fertilizer use, animal wastes from livestock feedlots, and discharge from sewage treatment plants results in **eutrophication** (overenrichment) of waterways.

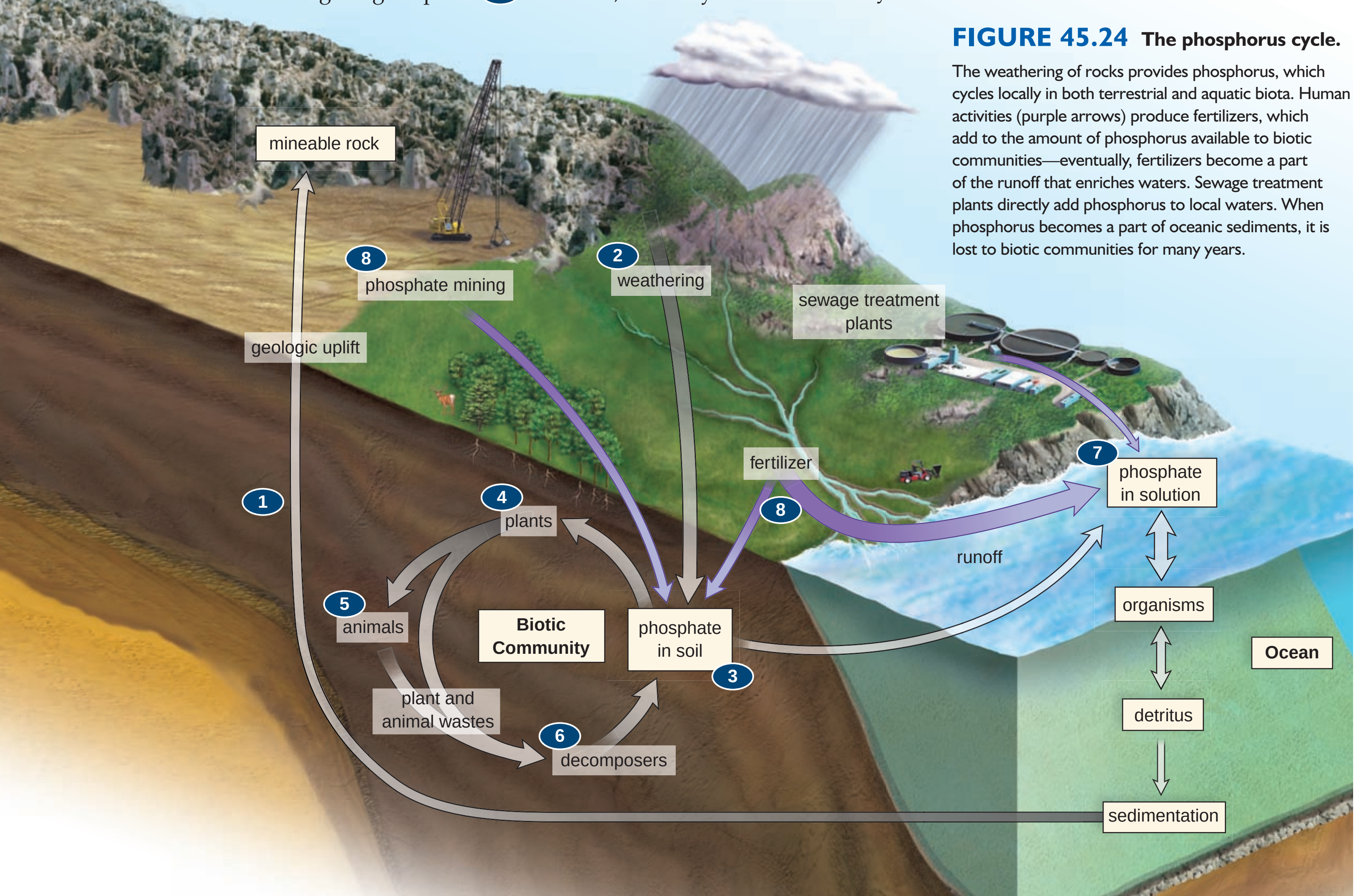


FIGURE 45.24 The phosphorus cycle.

The weathering of rocks provides phosphorus, which cycles locally in both terrestrial and aquatic biota. Human activities (purple arrows) produce fertilizers, which add to the amount of phosphorus available to biotic communities—eventually, fertilizers become a part of the runoff that enriches waters. Sewage treatment plants directly add phosphorus to local waters. When phosphorus becomes a part of oceanic sediments, it is lost to biotic communities for many years.

science focus

Ozone Shield Depletion

In the stratosphere, some 50 km above the Earth, ozone forms the **ozone shield,** a layer of ozone that absorbs most of the ultraviolet (UV) rays of the sun so that fewer rays strike the Earth. Ozone forms when ultraviolet radiation from the sun splits oxygen molecules (O_2), and then the oxygen atoms (O) combine with other oxygen molecules to produce ozone (O_3).

Cause of Depletion

The absorption of UV radiation by the ozone shield is critical for living things. In humans, UV radiation causes mutations that can lead to skin cancer and can make the lens of the eye develop cataracts. In addition, it adversely affects the immune system and our ability to resist infectious diseases. UV radiation also impairs crop and tree growth and kills off algae and tiny shrimplike animals (krill) that sustain oceanic life. Without an adequate ozone shield, therefore, our health and food sources are threatened.

It became apparent in the 1980s that depletion of ozone had occurred worldwide and that the depletion was most severe above the Antarctic every spring. There, ozone depletion became so great that it covered an area two and a half times the size of Europe, and exposed not only Antarctica but also the southern tip of South America and vast areas of the Pacific and Atlantic oceans to harmful ultraviolet rays. In the popular press, severe depletions of the ozone layer are called ozone holes (Fig. 45C*a*). Of even greater concern, an ozone hole has now appeared above the Arctic as well, and ozone holes were also detected within northern and southern latitudes, where many people live. Whether or not these holes develop in the spring depends on prevailing winds, weather conditions, and the type of particles in the atmosphere. A United Nations Environmental Program report predicts a 26% rise in cataracts and nonmelanoma skin cancers for every 10% drop in the ozone level. A 26% increase translates into 1.75 million additional cases of cataracts and 300,000 more skin cancers every year, worldwide.

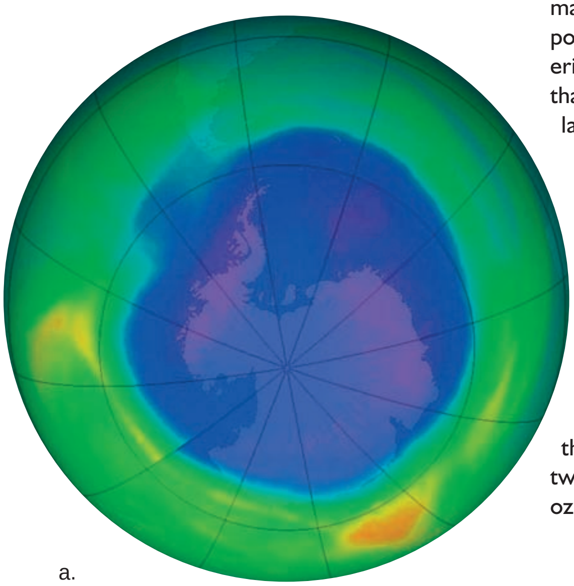
The seriousness of the situation caused scientists around the globe to begin studying the cause of ozone depletion. The cause was found to be chlorine atoms (Cl), which can destroy up to 100,000 molecules of ozone before settling to the Earth's surface as chloride years later.

Control of CFCs

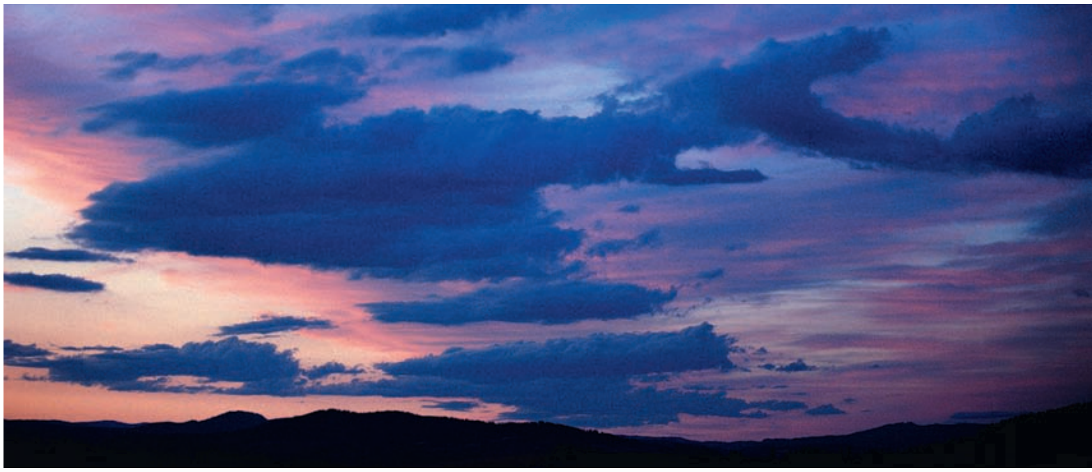
The chlorine atoms that enter the troposphere and eventually reach the stratosphere come primarily from the breakdown of **chlorofluorocarbons (CFCs),** chemicals much in use by humans. The best-known CFC is Freon, a coolant found in refrigerators and air conditioners. CFCs are also used as cleaning agents and as foaming agents during the production of Styrofoam coffee cups, egg cartons, insulation, and paddings. Formerly, CFCs were used as propellants in spray cans, but this application is now banned in the United States and several European countries. Other molecules, such as the cleaning solvent methyl chloroform, are also sources of harmful chlorine atoms.

Most of the countries of the world have stopped using CFCs, and the United States halted production in 1995. Since that time, satellite measurements indicate that the amount of harmful chlorine pollution in the stratosphere has started to decline. It is clear, however, that recovery of the ozone shield may take several more years and involve other pollution-fighting approaches, aside from lowering chlorine pollution. Researchers report that currently, there were more and longer-lasting polar clouds than previously. Why might that be? As the Earth's surface warms due to global warming, less heat reradiates into the stratosphere. Mathematical modeling suggests that stratospheric clouds could last twice as long over the Arctic before the year 2010, when the coldest winter ever is expected.

Cloud cover contributes to the breakdown of the ozone shield by chlorine pollution (Fig. 45C*b*). It is speculated that once polar stratospheric clouds become twice as persistent, there could still be an ozone loss of 30%.



a.



b.

FIGURE 45C Ozone shield depletion.
a. *Map of ozone levels in the atmosphere of the Southern Hemisphere, September 2007. The ozone depletion is larger than the size of Europe.* ***b.*** *Global warming is contributing to a cloud cover in the stratosphere, which contributes to the breakdown of the ozone shield by chlorine pollution.*

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The Nitrogen Cycle

Nitrogen gas (N_2) makes up about 78% of the atmosphere, but plants cannot make use of nitrogen in its gaseous form. Therefore, nitrogen can be a nutrient that limits the amount of growth in an ecosystem. First, let's consider that (1) **N_2 (nitrogen) fixation** occurs when nitrogen gas (N_2) is converted to ammonium (NH_4^+), a form plants can use (Fig. 45.25). Some cyanobacteria in aquatic ecosystems and some free-living bacteria in soil are able to fix atmospheric nitrogen in this way. Other nitrogen-fixing bacteria live in nodules on the roots of legumes, such as beans, peas, and clover. They make organic compounds containing nitrogen available to the host plants so that the plant can form proteins and nucleic acids. (2) Plants can also use nitrates (NO_3^-) as a source of nitrogen. The production of nitrates during the nitrogen cycle is called **nitrification.** Nitrification can occur in two ways: (1) Nitrogen gas (N_2) is converted to NO_3^- in the atmosphere when cosmic radiation, meteor trails, and lightning provide the high energy needed for nitrogen to react with oxygen. (2) Ammonium (NH_4^+) in the soil from various sources, including decomposition of organisms and animal wastes, is converted to NO_3^- by nitrifying bacteria in soil. Specifically, NH_4^+ (ammonium) is converted to NO_2^- (nitrite), and then NO_2^- is converted to NO_3^- (nitrate). (3) During the process of assimilation, plants take up NH_4^+ and NO_3^- from the soil and use these ions to produce proteins and nucleic acids. Notice in Figure 45.25 that the subcycle involving the biotic community, which occurs on land and in the ocean, need not depend on the presence of nitrogen gas at all. Finally, (4) **denitrification** is the conversion of nitrate back to nitrogen gas, which then enters the atmosphere. Denitrifying bacteria living in the anaerobic mud of lakes, bogs, and estuaries carry out this process as a part of their own metabolism. In the nitrogen cycle, denitrification would counterbalance nitrogen fixation if not for human activities.

Human Activities and the Nitrogen Cycle

(5) Humans significantly alter the transfer rates in the nitrogen cycle by producing fertilizers from N_2—in fact, they nearly double the fixation rate. Fertilizer, which also contains phosphate, runs off into lakes and rivers and results in an overgrowth of algae and rooted aquatic plants. When the algae die off, enlarged populations of decomposers use up all the oxygen in the water, and the result is a massive fish kill.

Acid deposition occurs because nitrogen oxides (NO_x) and sulfur dioxide (SO_2) enter the atmosphere from the burning of fossil fuels. Both these gases combine with water vapor to form acids that eventually return to the Earth. Acid deposition has drastically affected forests and lakes in northern Europe, Canada, and the northeastern United States because their soils are naturally acidic and their surface waters are only mildly alkaline (basic). Acid deposition reduces agricultural yields and corrodes marble, metal, and stonework.

Check Your Progress 45.3

1. What type of population is at the base of an ecological pyramid and the start of a food chain?
2. How does the passage of energy differ from that of chemicals in an ecosystem?
3. Human activities intensify what natural process associated with the carbon cycle?

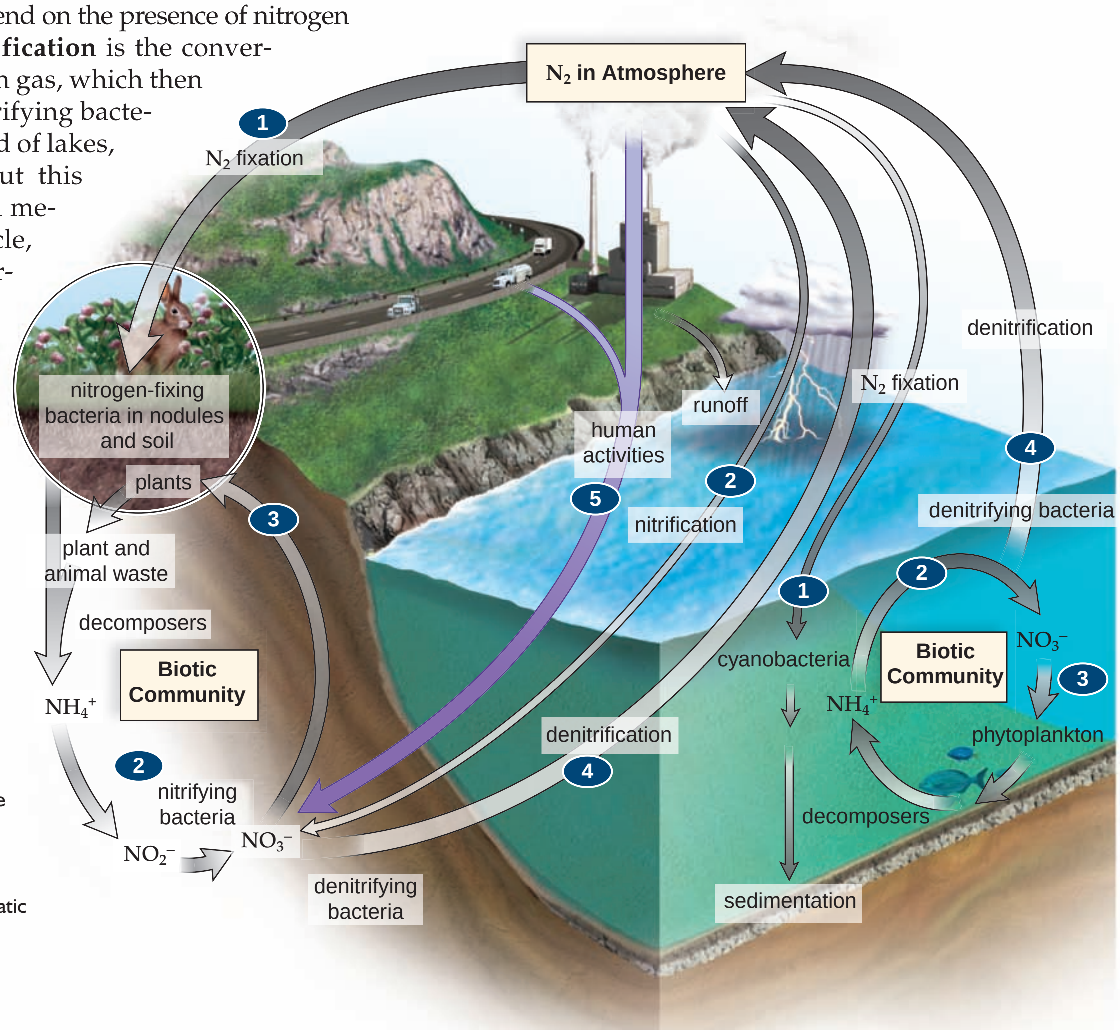

FIGURE 45.25 The nitrogen cycle.

Nitrogen is primarily made available to biotic communities by internal cycling of the element. Without human activities, the amount of nitrogen returned to the atmosphere (denitrification in terrestrial and aquatic communities) exceeds withdrawal from the atmosphere (N_2 fixation and nitrification). Human activities (purple arrows) result in an increased amount of NO_3^- in terrestrial communities with resultant runoff to aquatic biotic communities.

Connecting the Concepts

Community ecology is concerned with how populations interact with each other in a particular locale. Historically, some ecologists felt that communities functioned as "superorganisms," with each population a vital and integral part of the community. At the other extreme, some ecologists felt that each population simply occurred where conditions were best for it and that communities were chance aggregations of species. Most likely, the truth lies somewhere in between these two extreme views. We know that a population of any species is distributed where conditions are best for it. However, communities do exhibit emergent properties that result from certain groupings of species co-occurring.

The number of individuals in many populations within ecological communities is determined by interactions such as interspecific competition, predation, and parasitism. The sizes of all populations are negatively affected by at least one of those interactions. Positive interactions such as mutualisms are fairly common in nature (especially for plants), but their effect on population size is not well understood yet.

Perhaps one of the most important recent discoveries about communities is that they are highly dynamic. The number of species, kinds of species, and sizes of populations within most communities are constantly changing due to disturbances and climatic variability.

Because the species composition of communities can be so variable, many ecologists study the movement of energy and nutrients through communities. The physical environment has a large influence on energy and nutrient flow, and thus the nonliving world must be incorporated into our studies of communities and ecosystems.

summary

45.1 Ecology of Communities

A community is an assemblage of populations interacting with one another within the same environment. Communities differ in their composition (species found there) and their diversity (species richness and relative abundance).

An organism's habitat is where it lives in the community. An ecological niche is defined by the role an organism plays in its community, including its habitat and how it interacts with other species in the community. Competition, predator-prey, parasite-host, commensalistic, and mutualistic relationships help organize populations into an intricate dynamic system.

The competitive exclusion principle states that no two species can indefinitely occupy the same niche at the same time. Character displacement is a structural change that gives evidence of resource partitioning and niche specialization When resources are partitioned between two or more species, increased niche specialization occurs. But the difference between species can be more subtle, as when warblers feed at different parts of the tree canopy. Barnacles competing on the Scottish coast may be an example of present ongoing competition.

Predator-prey interactions between two species are especially influenced by amount of predation and the amount of food for the prey. A cycling of population densities may occur. Prey defenses take many forms: Camouflage, use of fright, and warning coloration are three possible mechanisms. Batesian mimicry occurs when one species has the warning coloration but lacks the defense. Müllerian mimicry occurs when two species with the same warning coloration have the same defense. We would expect coevolution to occur within a community. For example, the better the predator becomes at catching prey, the better the prey becomes at escaping the predator.

Like predators, parasites take nourishment from their host. Whether parasites are aggressive (kill their host) or benign probably depends on which results in the highest fitness. Symbiotic relationships are classified as commensalistic, parasitic, or mutualistic. Mutualistic relationships as when Clark's nuthatches feed on but disperse whitebark pine seeds are critical to the cohesiveness of a community.

45.2 Community Development

Ecological succession involves a series of species replacements in a community. Primary succession occurs where there is no soil present. Secondary succession occurs where soil is present and certain plant species can begin to grow. A climax community forms when stages of succession lead to a particular type of community.

45.3 Dynamics of an Ecosystem

Ecosystems have biotic and abiotic components. The biotic components are autotrophs, heterotrophs, detritus feeders, and decomposers. Abiotic components are resources such as nutrients and conditions such as type of soil and temperature.

Ecosystems are characterized by energy flow and chemical cycling. Energy flows because as food passes from one population to the next, each population makes energy conversions that result in a loss of usable energy. Chemicals cycle because they pass from one population to the next until decomposers return them once more to the producers. Ecosystems contain food webs in which the various organisms are connected by trophic relationships. In grazing food webs, food chains begin with a producer. In a detrital food web, food chains begin with detritus. Ecological pyramids are graphic representations of the number of organisms, biomass, or energy content of trophic levels.

Biogeochemical cycles may be sedimentary (phosphorus cycle) or gaseous (carbon and nitrogen cycles). Chemical cycling involves a reservoir, an exchange pool, and a biotic community.

In the water cycle, evaporation over the ocean is not compensated for by precipitation. Precipitation over land results in bodies of fresh water plus groundwater, including aquifers. Eventually, all water returns to the oceans.

In the carbon cycle, carbon dioxide in the atmosphere is an exchange pool; both terrestrial and aquatic plants and animals exchange carbon dioxide with the atmosphere. Living and dead organisms serve as reservoirs for the carbon cycle because they contain organic carbon. Human activities increase the level of CO_2 and other greenhouse gases contributing to global warming.

In the phosphorus cycle, geological upheavals move phosphorus from the ocean to land. Slow weathering of rocks returns phosphorus to the soil. Most phosphorus is recycled within a community, and phosphorus is a limiting nutrient.

In the nitrogen cycle, plants cannot use nitrogen gas from the atmosphere. During nitrogen fixation, N_2 converts to ammonium, making nitrogen available to plants. Nitrification is the production of nitrates while denitrification is the conversion of nitrate back to N_2, which enters the atmosphere. Human activities increase transfer

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rates in the nitrogen cycle. Acid deposition occurs when nitrogen oxides enter the atmosphere, combine with water vapor, and return to Earth in precipitation.

understanding the terms

acid deposition 861
autotroph 852
biogeochemical cycle 856
biomass 855
camouflage 845
carnivore 852
character displacement 842
chlorofluorocarbon (CFC) 860
climax community 850
coevolution 847
commensalism 846
community 840
competitive exclusion principle 842
consumer 852
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ecological succession 850
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parasitism 846
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predation 843
predator 843
prey 843
producer 852
resource partitioning 842
species diversity 840
species richness 840
symbiosis 846
transfer rate 857
trophic level 855
water (hydrologic) cycle 857

Match the terms to these definitions:

a. ______________ Complex pattern of interlocking and crisscrossing food chains.
b. ______________ Place where an organism lives and is able to survive and reproduce.
c. ______________ Directional pattern of change in which one community replaces another until a community typical of the area results.
d. ______________ Process by which atmospheric nitrogen gas is changed to forms that plants can use.

reviewing this chapter

1. What data do you need to describe a community's composition and diversity? 840–41
2. Describe the habitat and ecological niche of a particular species. 841
3. What is the competitive exclusion principle? How does the principle relate to character displacement and niche specialization? 842–43
4. Explain the observation that some predator-prey population densities cycle. Give examples of prey defenses. What is mimicry, and why does it work as a prey defense? 843–45
5 Give examples of parasitism, commensalism, and mutualism, and examples of coevolution that occur within a community. 846–48
6. What are the two types of ecological succession? What is the present controversy surrounding the concept? 850–51
7. Give examples of autotrophs and heterotrophs in an ecosystem. 852
8. Distinguish between energy flow and chemical cycling in an ecosystem. Describe two types of food webs and give examples of food chains. 853–54
9. Explain the appearance of an ecological pyramid and the expression trophic level. 855–56
10. Draw diagrams to illustrate the water, carbon, phosphorous, and nitrogen cycles. 857–61
11. List and explain human activities that affect each of these cycles and contribute to a degraded environment for all organisms. 857–61

testing yourself

Choose the best answer for each question.

1. According to the competitive exclusion principle,
   a. one species is always more competitive than another for a particular food source.
   b. competition excludes multiple species from using the same food source.
   c. no two species can occupy the same niche at the same time.
   d. competition limits the reproductive capacity of species.
2. Resource partitioning pertains to
   a. niche specialization.
   b. character displacement.
   c. increased species diversity.
   d. the development of mutualism.
   e. All but d are correct.

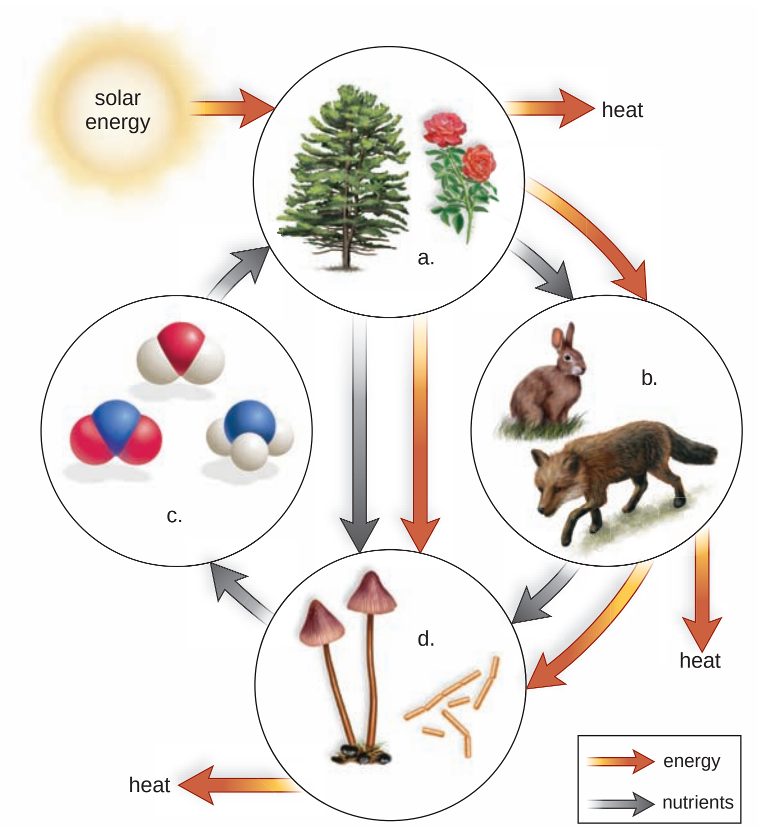
For statements 3–7, indicate the type of interaction in the key that is described in each scenario.

KEY:

a. competition
b. predation
c. parasitism
d. commensalism
e. mutualism

3. An alfalfa plant gains fixed nitrogen from the bacterial species *Rhizobium* in its root system, while *Rhizobium* gains carbohydrates from the plant.
4. Both foxes and coyotes in an area feed primarily on a limited supply of rabbits.
5. Roundworms establish a colony inside a cat's digestive tract.
6. A fungus captures nematodes as a food source.
7. An orchid plant lives in the treetops, gaining access to sun and pollinators, but not harming the trees.
8. A bullhorn acacia provides a home and nutrients for ants. Which statement is likely?
   a. The plant is under the control of pheromones produced by the ants.
   b. The ants protect the plant.
   c. The plant and the ants compete with each other.
   d. The plant and the ants have coevolved to occupy different ecological niches.
   e. All of these are correct.
9. The frilled lizard of Australia suddenly opened its mouth wide and unfurled folds of skin around its neck. Most likely, this was a way to
   a. conceal itself.
   b. warn that it was noxious to eat.
   c. scare a predator.
   d. scare its prey.
   e. All of these are correct.

10. When one species mimics another species, the mimic sometimes
    a. lacks the defense of the model.
    b. possesses the defense of the model.
    c. is brightly colored.
    d. All of these are correct.
11. The species within a community are
    a. used to compare communities.
    b. present due to their abiotic requirements.
    c. more diverse as the size of the area increases.
    d. present due to their biotic interactions.
    e. All of these are correct.
12. Label this diagram of an ecosystem:



13. Mosses growing on bare rock will eventually help to create soil. These mosses are involved in ______________ succession.
    a. primary
    b. secondary
    c. tertiary
14. The ecological niche of an organism
    a. is the same as its habitat.
    b. includes how it competes and acquires food.
    c. is specific to the organism.
    d. is usually occupied by another species.
    e. Both b and c are correct.
15. In what way are decomposers like producers?
    a. Either may be the first member of a grazing or a detrital food chain.
    b. Both produce oxygen for other forms of life.
    c. Both require nutrient molecules and energy.
    d. Both are present only on land.
    e. Both produce organic nutrients for other members of ecosystems.
16. When a heterotroph takes in food, only a small percentage of the energy in that food is used for growth because
    a. some food is not digested and is eliminated as feces.
    b. some metabolites are excreted as urine.
    c. some energy is given off as heat.
    d. All of these are correct.
    e. None of these are correct.
17. During chemical cycling, inorganic nutrients are typically returned to the soil by
    a. autotrophs.
    b. detritivores.
    c. decomposers.
    d. tertiary consumers.
18. In a grazing food web, carnivores that eat herbivores are
    a. producers.
    b. primary consumers.
    c. secondary consumers.
    d. tertiary consumers.
19. Choose the statement that is true concerning this food chain: grass → rabbits → snakes → hawks
    a. Each predator population has a greater biomass than its prey population.
    b. Each prey population has a greater biomass than its predator population.
    c. Each population is omnivorous.
    d. Each population returns inorganic nutrients and energy to the producer.
    e. Both a and c are correct.
    f. Both a and b are correct.
20. Which of the following is a sedimentary biogeochemical cycle?
    a. carbon
    b. nitrogen
    c. phosphorus
21. Which of the following could not be a component of the nitrogen cycle?
    a. proteins
    b. ammonium
    c. decomposers
    d. photosynthesis
    e. bacteria in root nodules
22. How do plants contribute to the carbon cycle?
    a. When plants respire, they release CO_2 into the atmosphere.
    b. When plants photosynthesize, they consume CO_2 from the atmosphere.
    c. When plants photosynthesize, they provide oxygen to heterotrophs.
    d. Both a and b are correct.

thinking scientifically

1. As per Figure 17.2, you observe three species of *Empidonax* flycatchers in the same general area, and you hypothesize that they occupy different niches. How could you substantiate your hypothesis?
2. In order to improve species richness, you decide to add phosphate to a pond. How might you determine how much phosphate to add in order to avoid eutrophication?

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.

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46

Major Ecosystems of the Biosphere

From space, the Earth is a pristine aqua globe, hovering against a vast backdrop of darkness. Get somewhat closer and the Earth's churning atmosphere, immense water systems, and seven continents come into view. Not until we see the surface can we make out the vast differences in land formations and physical features. Rainfall and temperature largely account for the great terrestrial ecosystems of the world, whether the freezing, snow-covered Arctic tundra, the hot scorched deserts, the lush tropical rain forests, or the sea of grass savanna.

In this chapter, we will study the mix of species in the major ecosystems already mentioned and also the oceans. Each species has a particular way of life and is adapted to living under particular environmental conditions. Through biogeochemical cycles driven by solar energy, natural ecosystems transformed the Earth's crust, its waters, and the atmosphere into a life-supporting environment.

Plants and animals from ecosystems of planet Earth.

concepts

46.1 Climate and the Biosphere

Climate refers to the prevailing weather conditions in a particular region. Climate is dictated by temperature and rainfall, which are influenced by the following factors: (1) variations in solar radiation distribution due to the tilt of the Earth as it orbits about the sun; and (2) other effects, such as topography and whether a body of water is nearby.

Effect of Solar Radiation

Because the Earth is a sphere, it receives a direct hit of the sun's rays at the equator but a glancing blow at the poles (Fig. 46.1*a*). The region between latitudes approximately 26.5° north and south of the equator is considered the tropics. The tropics are warmer than the areas north of 23.5°N and south of 23.5°S, known as the temperate regions. The tilt of the Earth as it orbits around the sun causes one pole or the other to be closer to the sun (except at the spring and fall equinoxes, when the sun aims directly at the equator), and this accounts for the seasons that occur in all parts of the Earth except at the equator (Fig. 46.1*b*). When the Northern Hemisphere is having winter, the Southern Hemisphere is having summer, and vice versa.

If the Earth were standing still and were a solid, uniform ball, all air movements—which we call winds—would be in two directions. Air at the equator warmed by the sun would rise and move toward colder air at the poles. Rising air creates zones of lower air pressure. However, because the Earth rotates on its axis daily and its surface consists of continents and oceans, the flows of warm and cold air are modified into three large circulation cells in each hemisphere (Fig. 46.2). At the equator, the sun heats the air and evaporates water. The warm, moist air rises, cools, and loses most of its moisture as rain. The greatest amounts of rainfall on Earth are near the equator. The rising air flows toward the poles, but at about 30° north and south latitude, it cools before it sinks toward the Earth's surface and reheats. As the dry air descends and warms, areas of high pressure are generated. High-pressure regions are zones of low rainfall. The great deserts of Africa, Australia, and the Americas occur at these latitudes. At the Earth's surface, the air flows both toward the poles and the equator. As dry air moves across the Earth, moisture from both land and water gets absorbed. At about 60° north and south latitude, the warmed air rises and cools, producing another low-pressure area with high rainfall. This moisture supports the great forests of the temperate zone. Part of this rising air flows toward the equator, and part continues toward the poles, where it descends. The poles are high pressure areas and have low amounts of precipitation.

Besides affecting precipitation, the spinning of the Earth also affects the winds (Fig. 46.2). In the Northern Hemisphere, large-scale winds generally bend clockwise, and in the Southern Hemisphere, they bend counterclockwise. The curving pattern of the winds, ocean currents, and cyclones is the result of the fact that the Earth rotates in an eastward direction. At about 30° north latitude and 30° south latitude, the winds blow from the east-southeast in the Southern Hemisphere and from the east-northeast in the Northern Hemisphere (the east coasts of continents at these latitudes are wet). The doldrums, regions of calm, occur at the equator. The winds blowing from the doldrums toward the poles are called trade winds because sailors depended on them to fill the sails of their trading ships. Between 30° and 60° north and south latitude, strong winds, called the prevailing westerlies, blow from west to east. The west coasts of the continents at these latitudes are wet, as is the Pacific Northwest, where a massive evergreen forest is located. Weaker winds, called the polar easterlies, blow from east to west at still higher latitudes of their respective hemispheres.

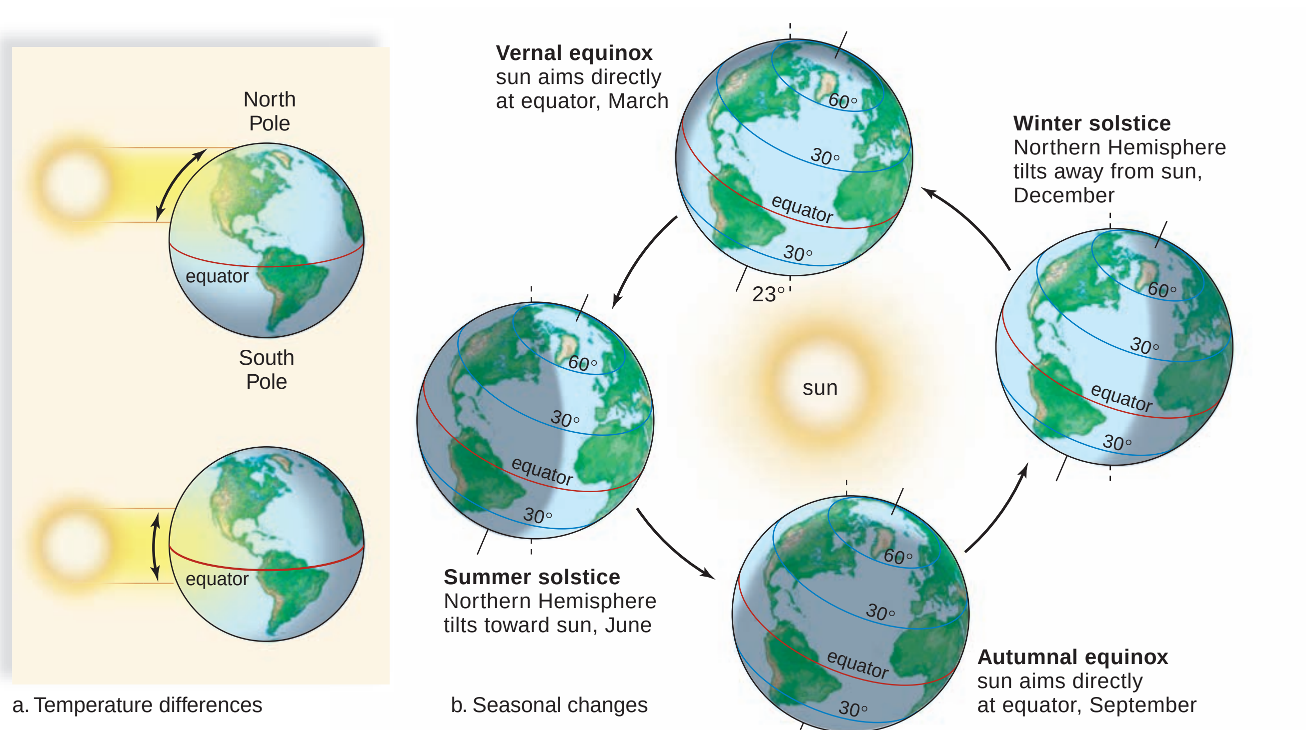

FIGURE 46.1 Distribution of solar energy.
a. Since the Earth is a sphere, beams of solar energy striking the Earth near one of the poles are spread over a wider area than similar beams striking the Earth at the equator. **b.** The seasons of the Northern and Southern Hemispheres are due to the tilt of the Earth on its axis as it rotates about the sun.

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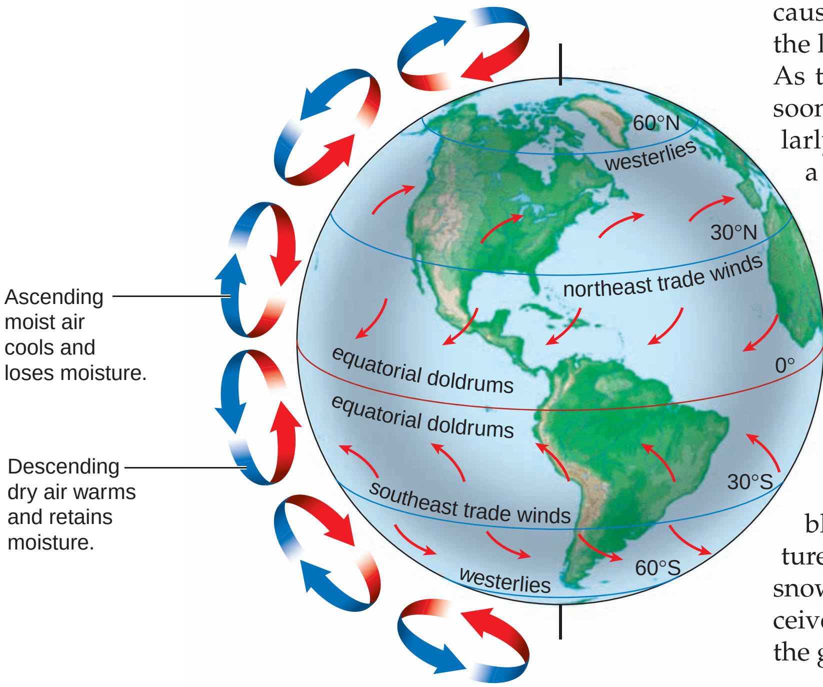


FIGURE 46.2 **Global wind circulation.**

Air ascends and descends as shown because the Earth rotates on its axis. Also, the trade winds move from the northeast to the west in the Northern Hemisphere, and from the southeast to the west in the Southern Hemisphere. The westerlies move toward the east.

Other Effects

Topography means the physical features, or "the lay," of the land. One physical feature that affects climate is the presence of mountains. As air blows up and over a coastal mountain range, it rises and cools. One side of the mountain, called the windward side, receives more rainfall than the other side, called the leeward side. On the leeward side, the air descends, absorbs moisture from the ground, and produces clear weather (Fig. 46.3). The difference between the windward side and the leeward side can be quite dramatic. In the Hawaiian Islands, for example, the windward side of the mountains receives more than 750 cm of rain a year, while the leeward side, which is in a **rain shadow,** gets on the average only 50 cm of rain and is generally sunny. In the United States, the western side of the Sierra Nevada Mountains is lush, while the eastern side is a semidesert.

The temperature of the oceans is more stable than that of landmasses. Oceanic water gains or loses heat more slowly than terrestrial environments. This causes coasts to have a unique weather pattern that is not observed inland. During the day, the land warms more quickly than the ocean, and the air above the land rises, pulling a cool sea breeze in from the ocean. At night, the reverse happens; the breeze blows from the land toward the sea.

India and some other countries in southern Asia have a **monsoon** climate, in which wet ocean winds blow onshore for almost half the year. The land heats more rapidly than the waters of the Indian Ocean during spring. The difference in temperature between the land and the ocean causes an enormous circulation of air: Warm air rises over the land, and cooler air comes in off the ocean to replace it. As the warm air rises, it loses its moisture, and the monsoon season begins. As just discussed, rainfall is particularly heavy on the windward side of hills. Cherrapunji, a city in northern India, receives an annual average of 1,090 cm of rain a year because of its high altitude. This weather pattern has reversed by November. The land is now cooler than the ocean; therefore, dry winds blow from the Asian continent across the Indian Ocean. In the winter, the air over the land is dry, the skies cloudless, and temperatures pleasant. The chief crop of India is rice, which starts to grow when the monsoon rains begin.

In the United States, people often speak of the "lake effect," meaning that in the winter, arctic winds blowing over the Great Lakes become warm and moisture-laden. When these winds rise and lose their moisture, snow begins to fall. Places such as Buffalo, New York, receive heavy snowfalls due to the lake effect, and snow is on the ground there for an average of 90–140 days every year.

Check Your Progress 46.1

1. What accounts for a warm climate at the equator?
2. Name two physical features that can affect rainfall.

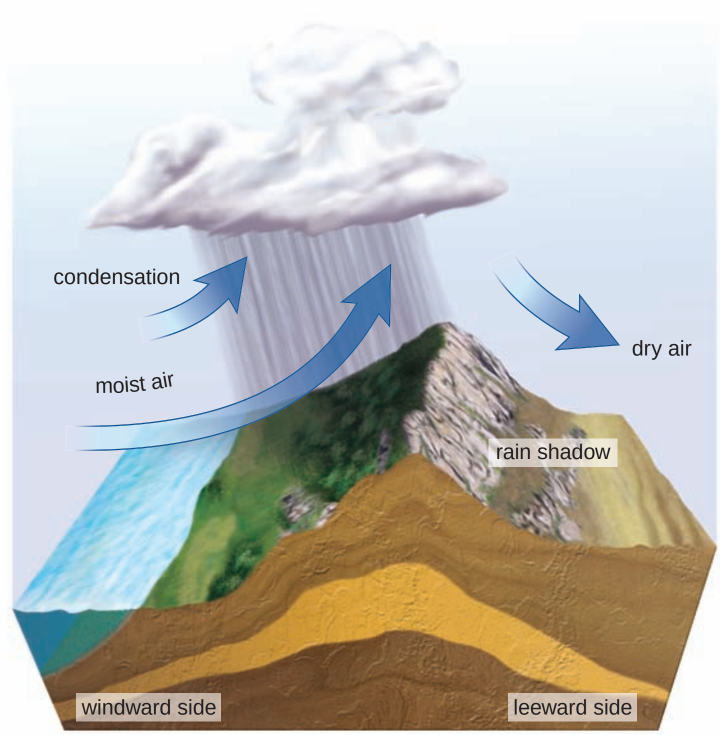
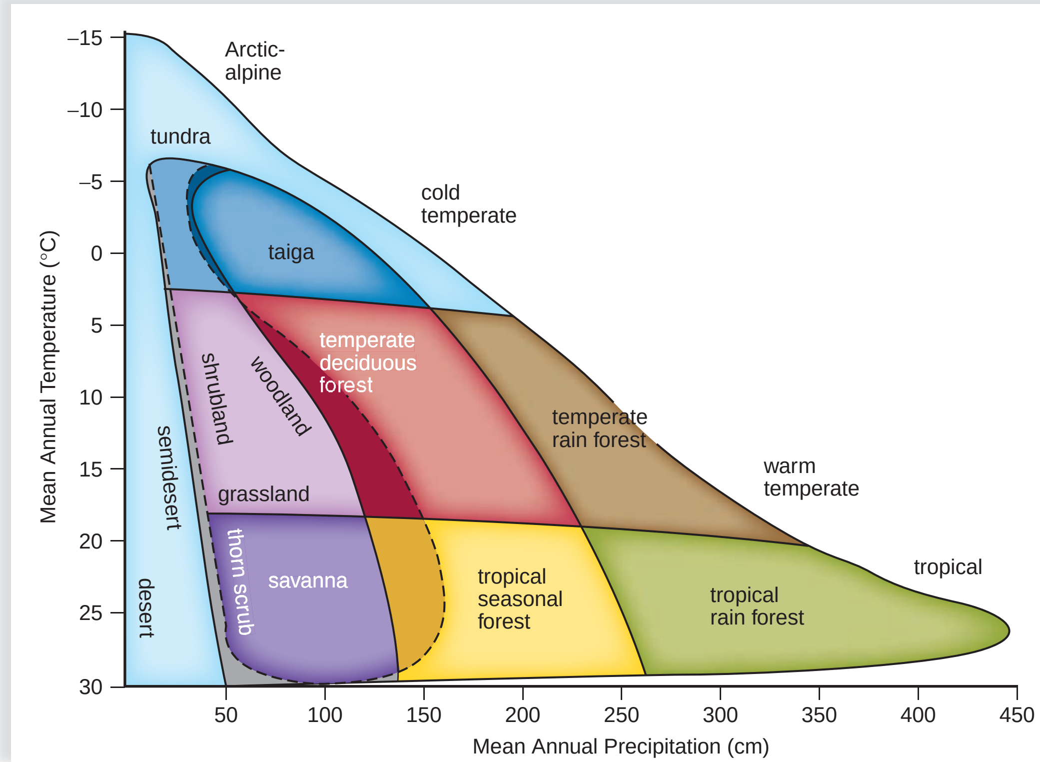


FIGURE 46.3 **Formation of a rain shadow.**

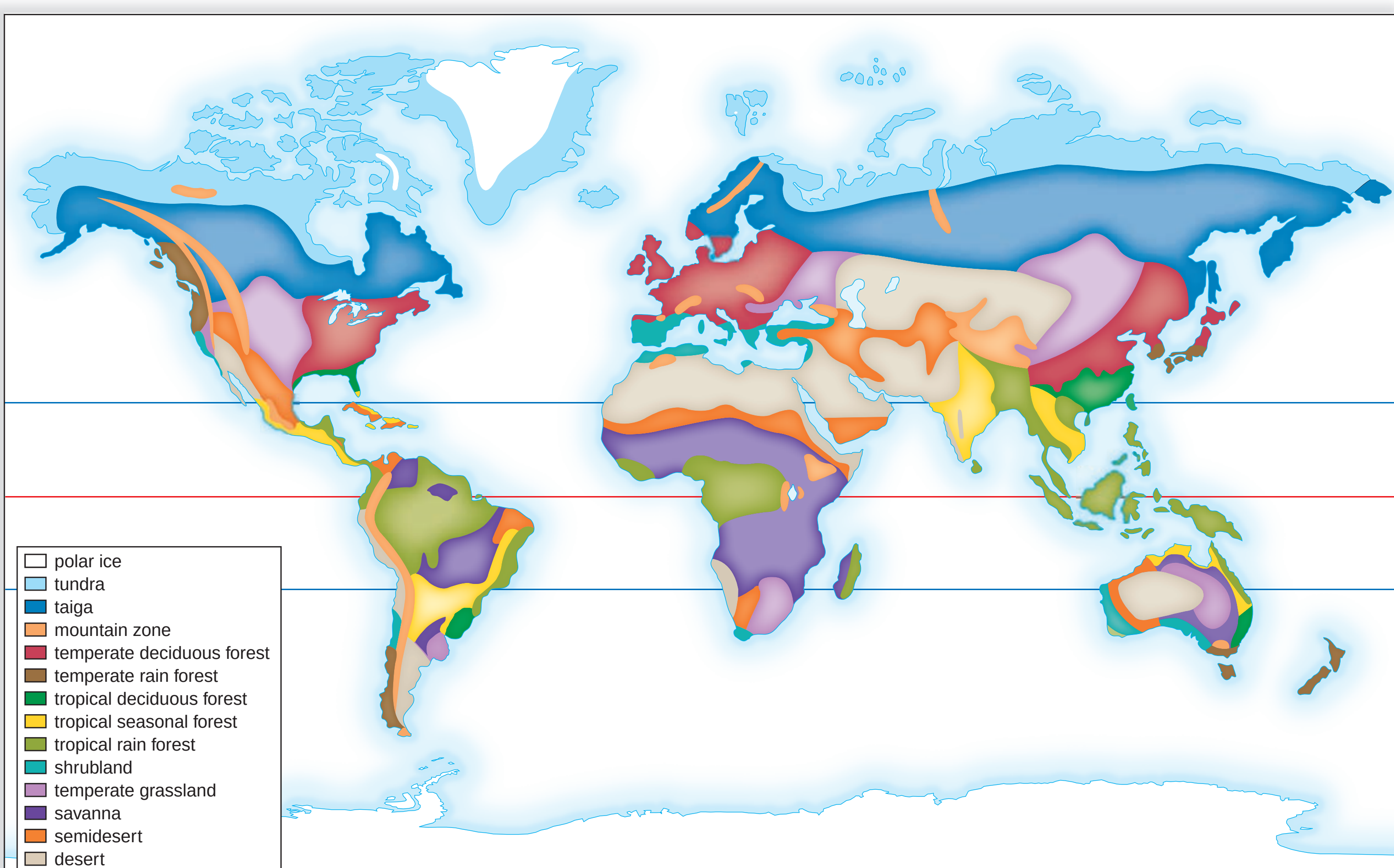
When winds from the sea cross a coastal mountain range, they rise and release their moisture as they cool this side of a mountain, called the windward side. The leeward side of a mountain receives relatively little rain and is therefore said to lie in a "rain shadow."

FIGURE 46.4 Pattern of biome distribution.

a. Pattern of world biomes in relation to temperature and moisture. The dashed line encloses a wide range of environments in which either grasses or woody plants can dominate the area, depending on the soil type. **b.** The same type of biome can occur in different regions of the world, as shown on this global map.



a. Biome pattern of temperature and precipitation



b. Distribution of biomes

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46.2 Terrestrial Ecosystems

TABLE 46.1

Selected Biomes

Name	*Characteristics*
Tundra	Around North Pole; average annual temperature is −12°C to −6°C; low annual precipitation (less than 25 cm); permafrost (permanent ice) year-round within a meter of surface.
Taiga (coniferous forest)	Large northern biome that circles just below the Arctic Circle; temperature is below freezing for half the year; moderate annual precipitation (30–85 cm); long nights in winter and long days in summer.
Temperate deciduous forest	Eastern half of United States, Canada, Europe, and parts of Russia; four seasons of the year with hot summers and cold winters; goodly annual precipitation (75–150 cm)
Grasslands	Called prairies in North America, savannas in Africa, pampas in South America, steppes in Europe; hot in summer and cold in winter (United States); moderate annual precipitation (25–50 cm); good soil for agriculture.
Tropical rain forests	Located near the equator in Latin America, Southeast Asia, and West Africa; warm (20–25°C) and wet (190 cm/year); has wet/dry season.
Deserts	Northern and Southern Hemispheres at 30° latitude; hot (38°C) days and cold (7°C) nights; low annual precipitation (less than 25 cm).

Major terrestrial ecosystems called a **biome** are characterized by their climate and geography (Table 46.1). A biome has a particular mix of plants and animals that are adapted to living under certain environmental conditions, of which climate is an overriding influence. When terrestrial biomes are plotted according to their mean annual temperature and mean annual precipitation, a particular pattern results (Fig. 46.4*a*). The distribution of biomes is shown in Figure 46.4*b*. Even though Figure 46.4 shows definite demarcations, keep in mind that the biomes gradually change from one type to the other. Also, although each type of biome will be described separately, remember that each biome has inputs from and outputs to all the other terrestrial and aquatic ecosystems of the biosphere.

The distribution of the biomes and their corresponding organismal populations are determined principally by differences in climate due to the distribution of solar radiation and defining topographical features. Both latitude and altitude are responsible for temperature gradients. If one travels from the equator to the North Pole, it is possible to observe first a tropical rain forest, followed by a temperate deciduous forest, a coniferous forest, and tundra, in that order, and this sequence is also seen when ascending a mountain (Fig. 46.5). The coniferous forest of a mountain is called a **montane coniferous forest,** and the tundra near the peak of a mountain is called an **alpine tundra.** When going from the equator to the South Pole, one would not reach a region corresponding to a coniferous forest and tundra of the Northern Hemisphere because the majority of the landmasses is shifted toward the north.

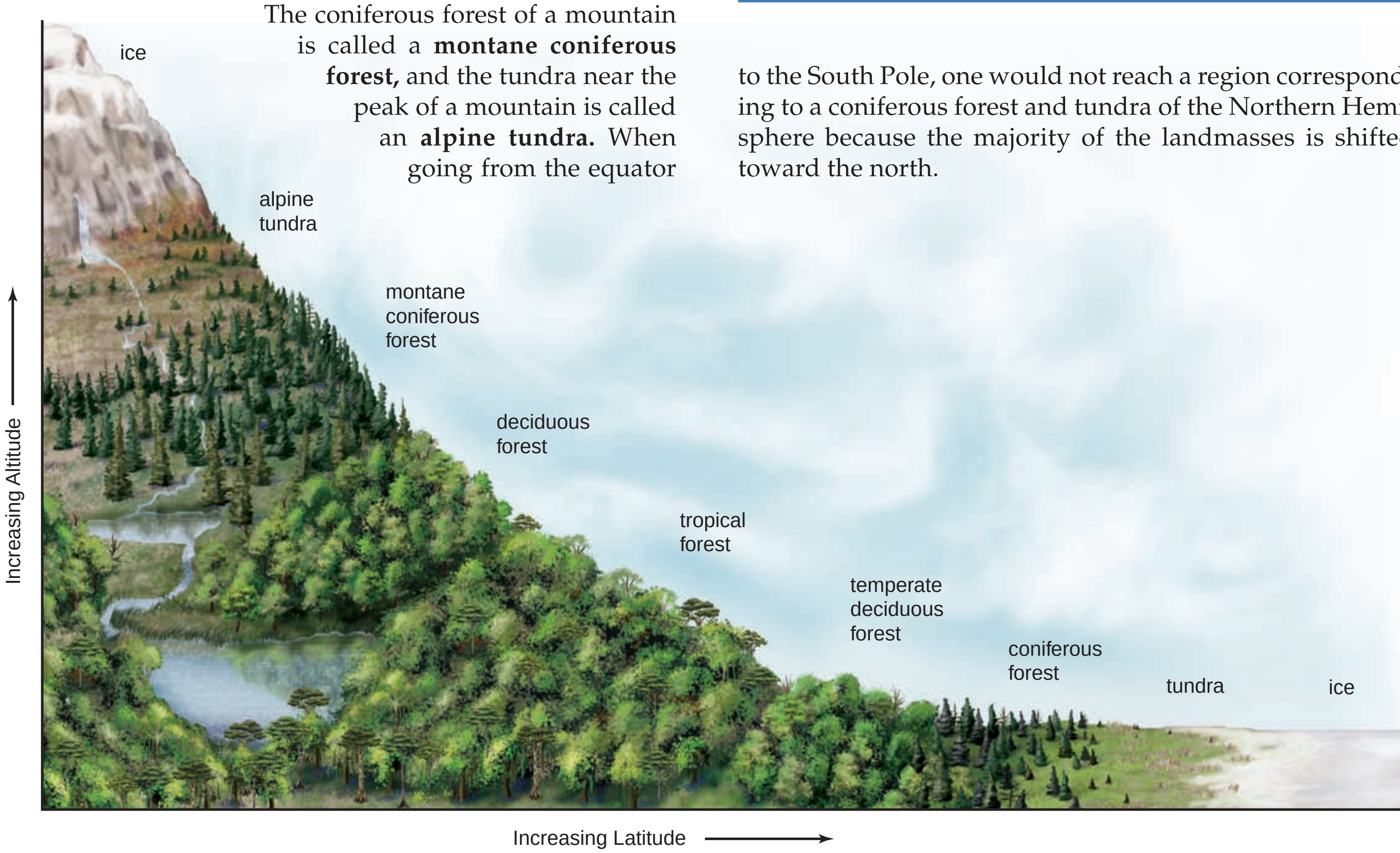


FIGURE 46.5 Climate and biomes.

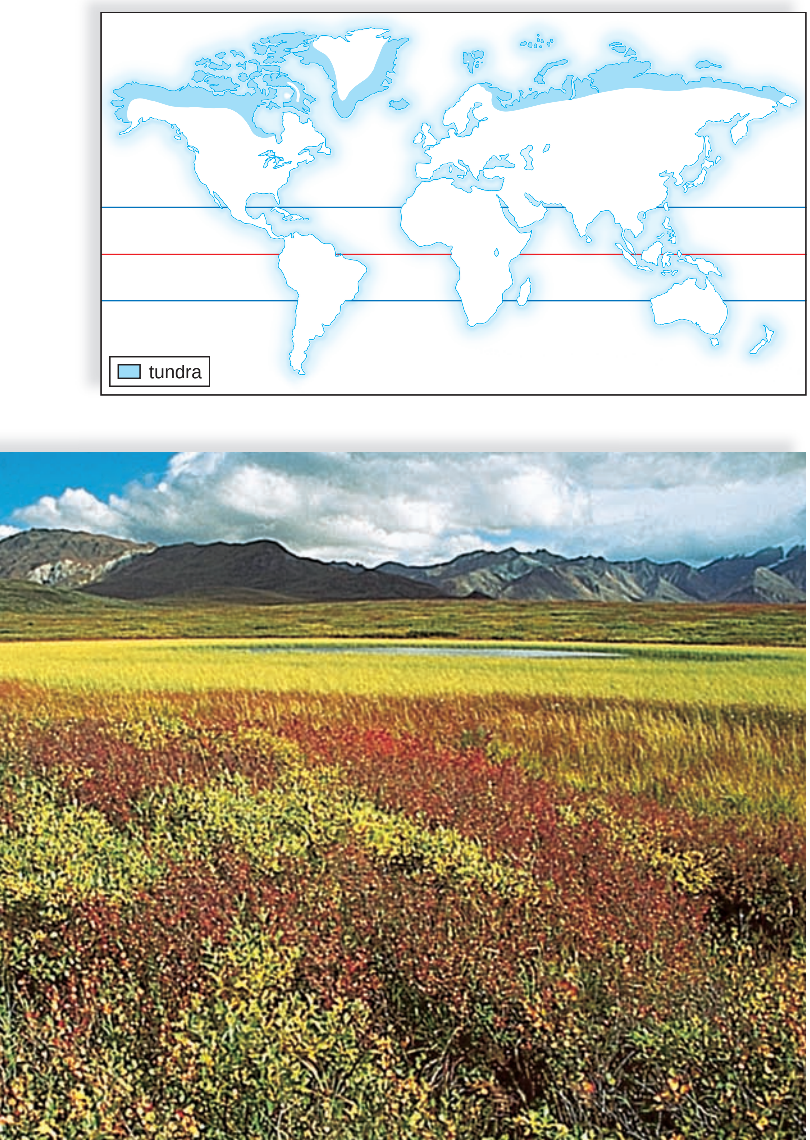
Biomes change with altitude just as they do with latitude because vegetation is partly determined by temperature. Precipitation also plays a significant role, which is one reason grasslands, instead of tropical or deciduous forests, are sometimes found at the base of mountains.

Tundra

The **Arctic tundra** biome, which encircles the Earth just south of ice-covered polar seas in the Northern Hemisphere, covers about 20% of the Earth's land surface (Fig. 46.6). (A similar ecosystem, called the alpine tundra, occurs above the timberline on mountain ranges.) The Arctic tundra is cold and dark much of the year. Arctic tundra has extremely long, cold, harsh winters and short summers (6–8 weeks). Because rainfall amounts to only about 20 cm a year, the tundra could possibly be considered a desert, but melting snow creates a landscape of pools and bogs in the summer, especially because so little evaporates. Only the topmost layer of soil thaws; the **permafrost** beneath this layer is always frozen, and therefore, drainage is minimal. The available soil in the tundra is nutrient-poor.

Trees are not found in the tundra because the growing season is too short, their roots cannot penetrate the permafrost, and they cannot become anchored in the shallow boggy soil of summer. In the summer, the ground is covered with short grasses and sedges, as well as numerous patches of lichens and mosses. Dwarf woody shrubs, such as dwarf birch, flower and seed quickly while there is plentiful sun for photosynthesis.

A few animals live in the tundra year-round. For example, the mouselike lemming stays beneath the snow; the ptarmigan, a grouse, burrows in the snow during storms; and the musk ox conserves heat because of its thick coat and short, squat body. Other animals that live in the tundra include snowy owls, lynx, voles, Arctic foxes, and snowshoe hares. In the summer, the tundra is alive with numerous insects and birds, particularly shorebirds and waterfowl that migrate inland. Caribou in North America and reindeer in Asia and Europe also migrate to and from the tundra, as do the wolves that prey upon them. Polar bears are common near the coastal regions. All species have adaptations for living in extreme cold and short growing or feeding seasons.



a. Tundra vegetation and location (light blue)

b. Plentiful bird life

c. Caribou, *Rangifer taradanus*, a large mammal

FIGURE 46.6 The tundra.

a. In this biome, which is nearest the polar regions, the vegetation consists principally of lichens, mosses, grasses, and low-growing shrubs. **b.** Pools of water that do not evaporate or drain into the permanently frozen ground attract many birds. **c.** Caribou, more plentiful in the summer than in the winter, feed on lichens, grasses, and shrubs.

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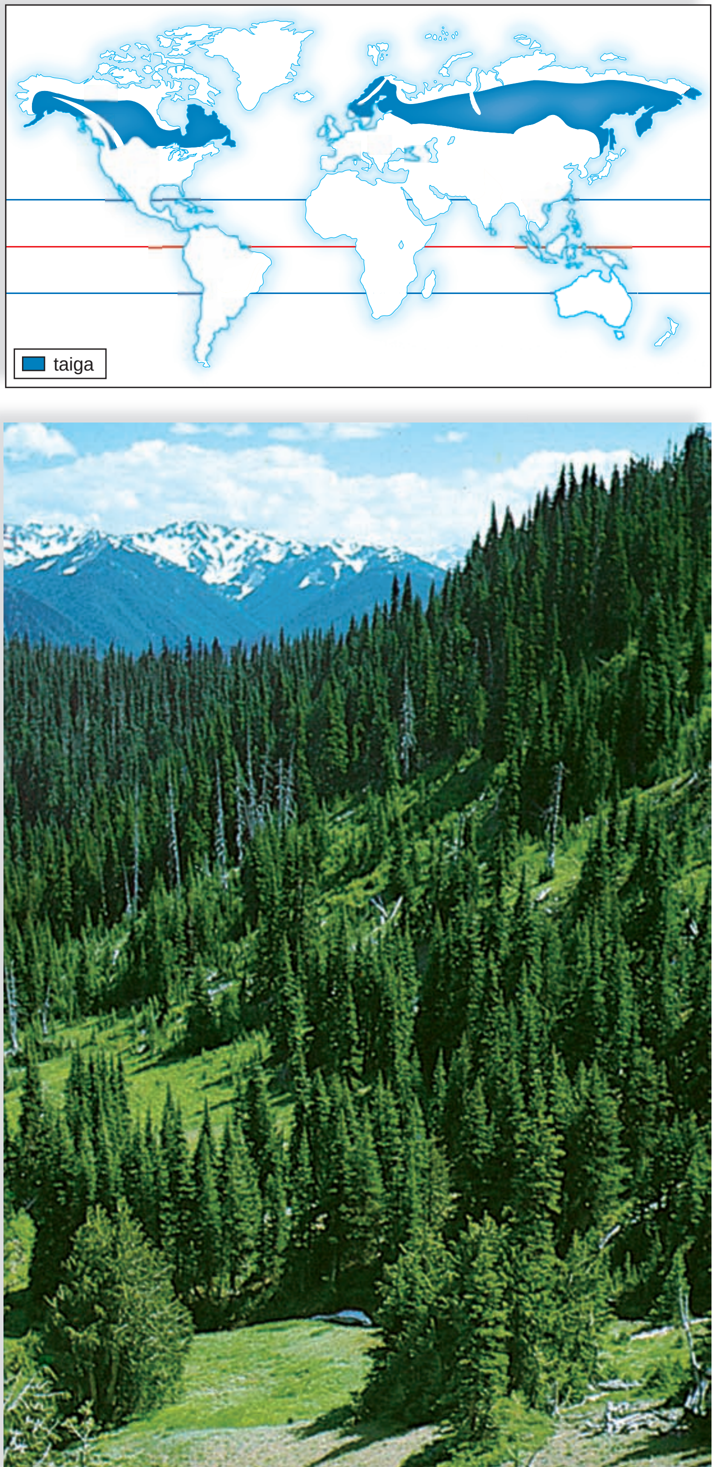


a. Taiga vegetation and location (dark blue)

b. Bull moose, *Alces americanus*, a large mammal

FIGURE 46.7 The taiga.

The taiga, which means swampland, spans northern Europe, Asia, and North America. The appellation "spruce-moose" refers to the (**a**) dominant presence of spruce trees and (**b**) moose, which frequent the ponds.

Coniferous Forests

Coniferous forests are found in three locations: in the **taiga,** which extends around the world in the northern part of North America and Eurasia; near mountaintops (where it is called a montane coniferous forest); and along the Pacific coast of North America, as far south as northern California.

The taiga, or boreal forest, exists south of the tundra and covers approximately 11% of the Earth's landmasses (Fig. 46.7). There are no comparable biomes in the Southern Hemisphere because no large landmasses exist at that latitude. The taiga typifies the coniferous forest with its cone-bearing trees, such as spruce, fir, and pine. These trees are well adapted to the cold because both the leaves and bark have thick coverings. Also, the needlelike leaves can withstand the weight of heavy snow. There is a limited understory of plants, but the floor is covered by low-lying mosses and lichens beneath a layer of needles. Birds harvest the seeds of the conifers, and bears, deer, moose, beavers, and muskrats live around the cool lakes and along the streams. Wolves prey on these larger mammals. A montane coniferous forest also harbors the wolverine and the mountain lion.

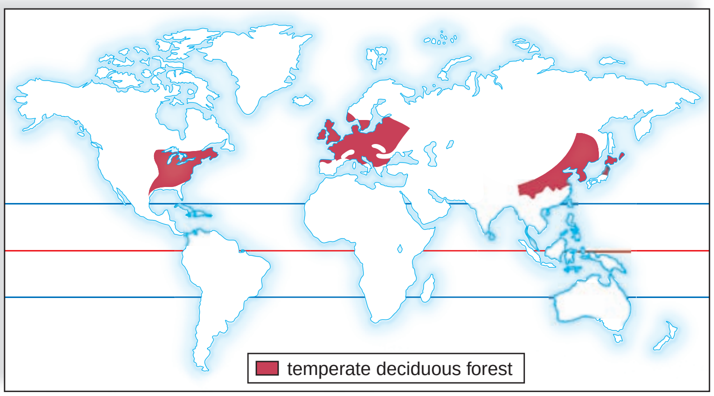
The coniferous forest that runs along the west coast of Canada and the United States is sometimes called a **temperate rain forest.** The prevailing winds moving in off the Pacific Ocean lose their moisture when they meet the coastal mountain range. The plentiful rainfall and rich soil have produced some of the tallest conifer trees ever in existence, including the coastal redwoods. This forest is also called an old-growth forest because some trees are as old as 800 years. It truly is an evergreen forest because mosses, ferns, and other plants grow on all the tree trunks. Squirrels, lynx, and numerous species of amphibians, reptiles, and birds inhabit the temperate rain forest. The northern spotted owl is an endangered species of this particular ecosystem that has received recent conservation efforts.

Temperate Deciduous Forests

Temperate deciduous forests are found south of the taiga in eastern North America, eastern Asia, and much of Europe (Fig. 46.8). The climate in these areas is moderate, with relatively high rainfall (75–150 cm per year). The seasons are well defined, and the growing season ranges between 140 and 300 days. The trees, such as oak, beech, sycamore, and maple, have broad leaves and are termed deciduous trees; they lose their leaves in the fall and grow them in the spring. In the southern temperate deciduous forests, evergreen magnolia trees can be found.

The tallest trees form a canopy, an upper layer of leaves that are the first to receive sunlight. Even so, enough sunlight penetrates to provide energy for another layer of trees, called understory trees. Beneath these trees are shrubs that may flower in the spring before the trees have put forth their leaves. Still another layer of plant growth—mosses, lichens, and ferns—resides beneath the shrub layer. This stratification provides a variety of habitats for insects and birds. Ground life is also plentiful. Squirrels, rabbits, woodchucks, and chipmunks are small herbivores. These and ground birds such as turkeys, pheasants, and grouse are preyed on by red foxes. White-tailed deer and black bears have increased in number in recent years. In contrast to the taiga, amphibians and reptiles occur in this biome because the winters are not as cold. Frogs and turtles prefer an aquatic existence, as do the beaver and muskrat, which are mammals.

Autumn fruits, nuts, and berries provide a supply of food for the winter, and the leaves, after turning brilliant colors and falling to the ground, contribute to the rich layer of humus. The minerals within the rich soil are washed far into the ground by spring rains, but the deep tree roots capture these and bring them back up into the forest system again.



a. Temperate deciduous vegetation and location (red)

Millipede, *Marceus* sp.

Eastern chipmunk, *Tamias striatus*

Marsh marigolds, *Caltha howellii*

Bobcat, *Felis rufus*

b. Animal life of forest biome

FIGURE 46.8 Temperate deciduous forest.

a. A temperate deciduous forest is home to many varied plants and animals. **b.** Millipedes can be found among leaf litter, chipmunks feed on acorns, and bobcats prey on these and other small mammals.

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ecology focus

Wildlife Conservation and DNA

After DNA analysis, scientists were amazed to find that some 60% of loggerhead turtles drowning in the nets and hooks of fisheries in the Mediterranean Sea were from beaches in the southeastern United States. Since the unlucky creatures were a good representative sample of the turtles in the area, that meant more than half of the young turtles living in the Mediterranean Sea had hatched from nests on beaches in Florida, Georgia, and South Carolina (Fig. 46A*a*). Some 20,000–50,000 loggerheads die each year due to the Mediterranean fisheries, which may partly explain the decline in loggerheads nesting on southeastern U.S. beaches for the last 25 years.

The sequencing of DNA from Alaskan brown bears allowed Sandra Talbot (a graduate student at the University of Alaska's Institute of Arctic Biology) and wildlife geneticist Gerald Shields to conclude that there are two types of brown bears in Alaska. One type resides only on southeastern Alaska's Admiralty, Baranof, and Chichagof Islands, known as the ABC Islands. The other brown bear in Alaska is found throughout the rest of the state, as well as in Siberia and western Asia (Fig. 46A*b*).

A third distinct type of brown bear, known as the Montana grizzly, resides in other parts of North America. These three types comprise all of the known brown bears in the New World.

The ABC bears' uniqueness may be bad news for the timber industry, which has expressed interest in logging parts of the ABC Islands. Says Shields, "Studies show that when roads are built and the habitat is fragmented, the population of brown bears declines. Our genetic observations suggest they are truly unique, and we should consider their heritage. They could never be replaced by transplants."

In what will become a classic example of how DNA analysis might be used to protect endangered species from future ruin, scientists from the United States and New Zealand carried out discreet experiments in a Japanese hotel room on whale sushi bought in local markets. Sushi, a staple of the Japanese diet, is a rice and meat concoction wrapped in seaweed. Armed with a miniature DNA sampling machine, the scientists found that, of the 16 pieces of whale sushi they examined, many were from whales that are endangered or protected under an international moratorium on whaling. "Their findings demonstrated the true power of DNA studies," says David Woodruff, a conservation biologist at the University of California, San Diego.

One sample was from an endangered humpback, four were from fin whales, one was from a northern minke, and another from a beaked whale. Stephen Palumbi of the University of Hawaii says the technique could be used for monitoring and verifying catches. Until then, he says, "no species of whale can be considered safe."

Meanwhile, Ken Goddard, director of the unique U.S. Fish and Wildlife Service Forensics Laboratory in Ashland, Oregon, is already on the watch for wildlife crimes in the United States and 122 other countries that send samples to him for analysis. "DNA is one of the most powerful tools we've got," says Goddard, a former California police crime-lab director.

The lab has blood samples, for example, for all of the wolves being released into Yellowstone National Park—"for the obvious reason that we can match those samples to a crime scene," says Goddard. The lab has many cases currently pending in court that he cannot discuss. But he likes to tell the story of the lab's first DNA-matching case. Shortly after the lab opened in 1989, California wildlife authorities contacted Goddard. They had seized the carcass of a trophy-sized deer from a hunter. They believed the deer had been shot illegally on a 3,000-acre preserve owned by actor Clint Eastwood. The agents found a gut pile on the property but had no way to match it to the carcass. The hunter had two witnesses to deny the deer had been shot on the preserve.

Goddard's lab analysis made a perfect match between tissue from the gut pile and tissue from the carcass. Says Goddard: "We now have a cardboard cutout of Clint Eastwood at the lab saying 'Go ahead: Make my DNA.' "

FIGURE 46A DNA studies.
a. *Many loggerhead turtles found in the Mediterranean Sea are from the southeastern United States.* ***b.*** *These two brown bears appear similar, but one type, known as an ABC bear, resides only on southeastern Alaska's Admiralty, Baranof, and Chichagof islands.*

a. Loggerhead turtle, *Caretta caretta*

b. Brown bears, *Ursus arctos*

Tropical Forests

In the **tropical rain forests** of South America, Africa, and the Indo-Malayan region near the equator, the weather is always warm (between 20° and 25°C), and rainfall is plentiful (with a minimum of 190 cm per year). This may be the richest biome, in terms of both number of different kinds of species and their abundance.

A tropical rain forest has a complex structure, with many levels of life, including the forest floor, understory, and canopy. The vegetation of the forest floor is very sparse because much of the sunlight is filtered out by the canopy. The understory consists of smaller plants that are specialized for life in the shade. The canopy, topped by the crowns of tall trees, is the most productive level of the tropical rain forest (Fig. 46.9). Some of the broadleaf evergreen trees grow from 15–50 m or more. These tall trees often have trunks buttressed at ground level to prevent their toppling over. Lianas, or woody vines, which encircle the tree as it grows, also help strengthen the trunk. The diversity of species is enormous—a 10-km^2 area of tropical rain forest may contain 750 species of trees and 1,500 species of flowering plants.

Although some animals live on the forest floor (e.g., pacas, agoutis, peccaries, and armadillos), most live in the trees (Fig. 46.10). Insect life is so abundant that the majority of species have not been identified yet. Termites play a vital role in the decomposition of woody plant material, and ants are found everywhere, particularly in the trees. The various birds, such as hummingbirds, parakeets, parrots, and toucans, are often beautifully colored. Amphibians and reptiles are well represented by many types of frogs, snakes, and lizards. Lemurs, sloths, and monkeys are well-known primates that feed on the fruits of the trees. The largest carnivores are the big cats—the jaguars in South America and the leopards in Africa and Asia.

Many animals spend their entire life in the canopy, as do some plants. **Epiphytes** are plants that grow on other plants but usually have roots of their own that absorb moisture and minerals leached from the canopy; others catch rain and debris by forming vases of overlapping leaves. The most common epiphytes are related to pineapples, orchids, and ferns.

While we usually think of tropical forests as being nonseasonal rain forests, tropical forests that have wet and

FIGURE 46.9 **Levels of life in a tropical rain forest.**

The primary levels within a tropical rain forest are the canopy, the understory, and the forest floor. But the canopy (solid layer of leaves) contains levels as well, and some organisms spend their entire life in one particular level. Long lianas (hanging vines) climb into the canopy, where they produce leaves. Epiphytes are air plants that grow on the trees but do not parasitize them.

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