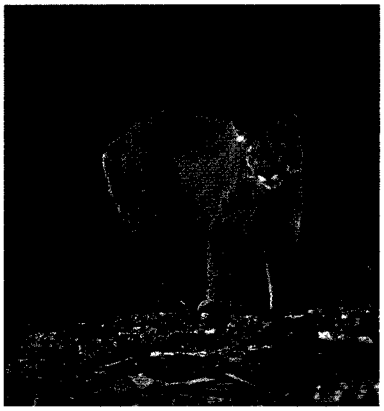
CHAPTER 15

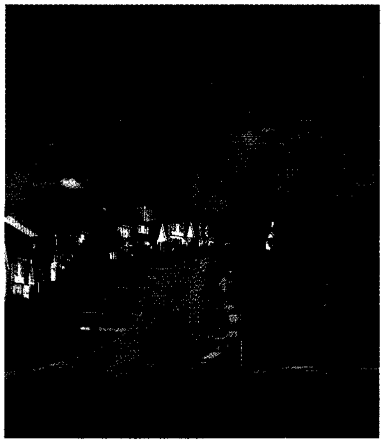
Where Do You Live?

Climate and Biomes

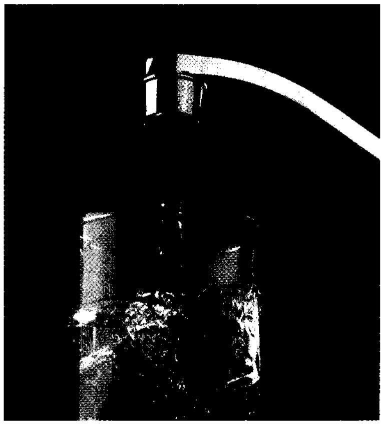
What is your "biological address?"



Who are your neighbors?



It can be difficult to identify a biological address in a human-designed landscape.



And it is sometimes difficult to determine where the resources on which we rely come from.

How do you answer the question, "Where do you live?" Most of us would respond with a neighborhood or street address to someone from our community, a city or town name to someone from elsewhere in our state, or a state or country name to someone who lives far away. Not too many of us would give a reply such as "the Sonoran Desert" or "the boreal forest." These descriptions of the natural environment in which we live can be thought of as biological addresses. Our biological addresses include the native vegetation and the resident animals, fungi, and microbes that share, or once shared, our living space.

In this chapter, we will explore factors that help to determine the qualities of a particular biological address by guiding you to learn more about your own natural neighborhood. See if you can answer the following questions:

- Is the native vegetation of the place where you live forest, grassland, or desert?
- What are the seasonal weather changes in your area?
- Can you describe the physical characteristics of three plant species that are native to your area?

- What is the largest mammalian predator that lives, or once lived, in the habitat that is now your neighborhood?
- Can you describe three native bird species that breed in your region?

Is it important to know the answers to questions like these? Consider that many Americans would have a difficult time answering at least some of these questions. Human settlements around the United States are remarkably similar, and many of us have little experience with local habitats in their pre-settlement condition. Knowing the answers to these questions implies bioregional awareness, an understanding of local environmental conditions. One consequence of a general lack of bioregional awareness that you may have experienced is local summertime water shortages caused by the intense thirst of suburban lawns, especially in areas where water-loving vegetation is not native. Other costs of lack of bioregional awareness may be more severe, including the construction of homes in areas where periodic fires are common, or building on sandy coastlines, which are very unstable in their natural condition. Having a solid awareness of one's own bioregion may allow people to build human settlements that are better both for humans and the natural environment. Taking into account one's bioregion when developing human habitats can occur in many ways; for example, in the southwest desert regions of the United States, environmentally sensitive housing developers use xeriscaping, a kind of landscaping that involves native, drought-tolerant plants. Xeriscaping not only prevents the overconsumption of water but also provides a habitat for resident wildlife.

Human populations, like all natural populations, require resources and produce waste. Despite our familiarity with human settlements in the United States, surprisingly few Americans have an understanding of where our resources come from and where our waste goes. In other words, we do not have a clear picture of the ecology of the human environment. See if you can answer these questions:

- What body of water serves as the source of your tap water?
- What primary agricultural crops are produced in your area?
- How is your electricity generated?
- Where does your garbage go?
- How is the waste handled when you flush the toilet or pour liquids down the drain?

Why is knowing the answers to these questions important? Humans remain dependent on the natural world for our resources and waste disposal. An understanding of the capacity of the natural environment in our bioregion can help us design ways of living that take advantage of a region's natural gifts and respect its limits. The consequences of a lack of understanding about how our human communities fit into the surrounding biological community can include air and water pollution and the negative effects of that pollution on ourselves and our biological neighbors. In this chapter, we explore how the ecology of a bioregion intersects with the biology of human habitats.

15.1 Global and Regional Climate

Why is Buffalo, New York so much snowier than frigid Winnipeg, Manitoba? Why is Miami, Florida hot and humid while Tuscon, Arizona is hot and dry? Why does much of India experience monsoons? Why are there greater temperature differences between winter and summer in Moscow, Russia than in Dublin, Ireland? Why is the daily high temperature on tropical Pacific islands always near 80°F? The answers to all of these questions require an understanding of **climate**, the average weather of a place as measured over many years. The climate of a place comprises various measures such as average temperature, average rainfall, and the average number of severe weather events in a given time period such as a month or a year. Climate should be distinguished from **weather**, which can be thought of as the current conditions in terms of temperature, cloud cover, and **precipitation** (rain or snowfall). Put another way, the weather in a place will tell you if you have to shovel snow tomorrow morning, while the climate in a place will tell you if you even need to own a snow shovel.

The major components of climate in a geographic area are temperature, precipitation, and the variability of these two factors. As you read this section, think about the climate of your hometown and see if you can identify the global and local factors that influence it.

Temperature

You already know that temperatures are warmer at Earth's equator than at its poles. You have also probably noticed that some areas of your region are consistently cooler or warmer than other areas. The temperature in any site depends on both its location on the globe and the local environment.

Global Temperature Patterns. On a broad scale, the average temperature of any spot on the globe is determined by the amount of **solar irradiance** it receives—that is, the amount of light energy per unit area hitting that spot. Locations that receive large amounts of solar irradiance in a year have a higher average temperature than places receiving small amounts. The amount of sun energy striking Earth's surface varies because of the planet's spherical shape. Figure 15.1 illustrates two streams of solar

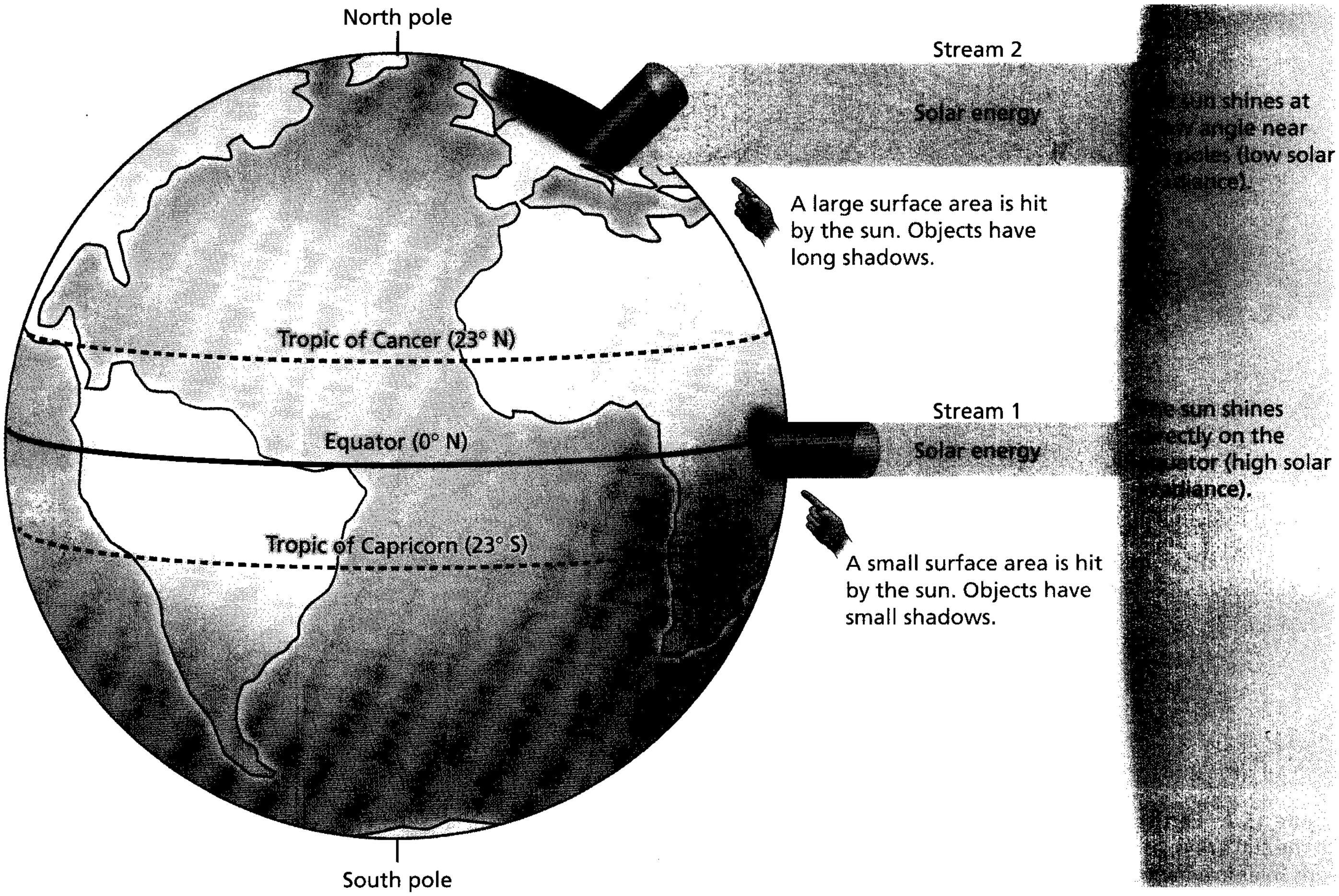


Figure 15.1 Solar irradiance on Earth's surface. The annual average temperature in a location on Earth's surface is most directly determined by its solar irradiance. Areas near the equator receive the greatest amount of solar energy (stream 1), while areas near the poles receive the least (stream 2).

energy flowing from the sun; both are the same diameter and equivalent in light energy content. Energy stream 1 strikes Earth's surface where it is facing directly toward the stream, while energy stream 2 strikes the surface where it is "curving away" from the sun. As you can see in the figure, the surface area hit by stream 1 is much smaller than the surface area hit by stream 2. In other words, the solar irradiance is greatest in areas that directly face the sun and lower in areas that curve away from the sun.

Earth's axis is roughly perpendicular to the flow of energy from the sun. The extremes of this axis are called **poles**, while the circle around the planet that is equidistant to both poles is called the **equator**. The position of the axis in relation to the sun's energy means that solar irradiance is greatest near the equator and declines gradually until it reaches its lowest levels at the poles. This is why southern Florida has a warmer climate than northern Vermont.

Solar irradiance also varies in a particular location on an annual basis. This occurs because Earth's axis is not exactly perpendicular to the sun's rays. In fact, the axis tilts approximately 23.5° from perpendicular (Figure 15.2). Due to this tilt, as Earth orbits the sun, the Northern Hemisphere (the region of the globe between the equator and the North Pole) is tilted toward the sun during the northern summer and away from the sun

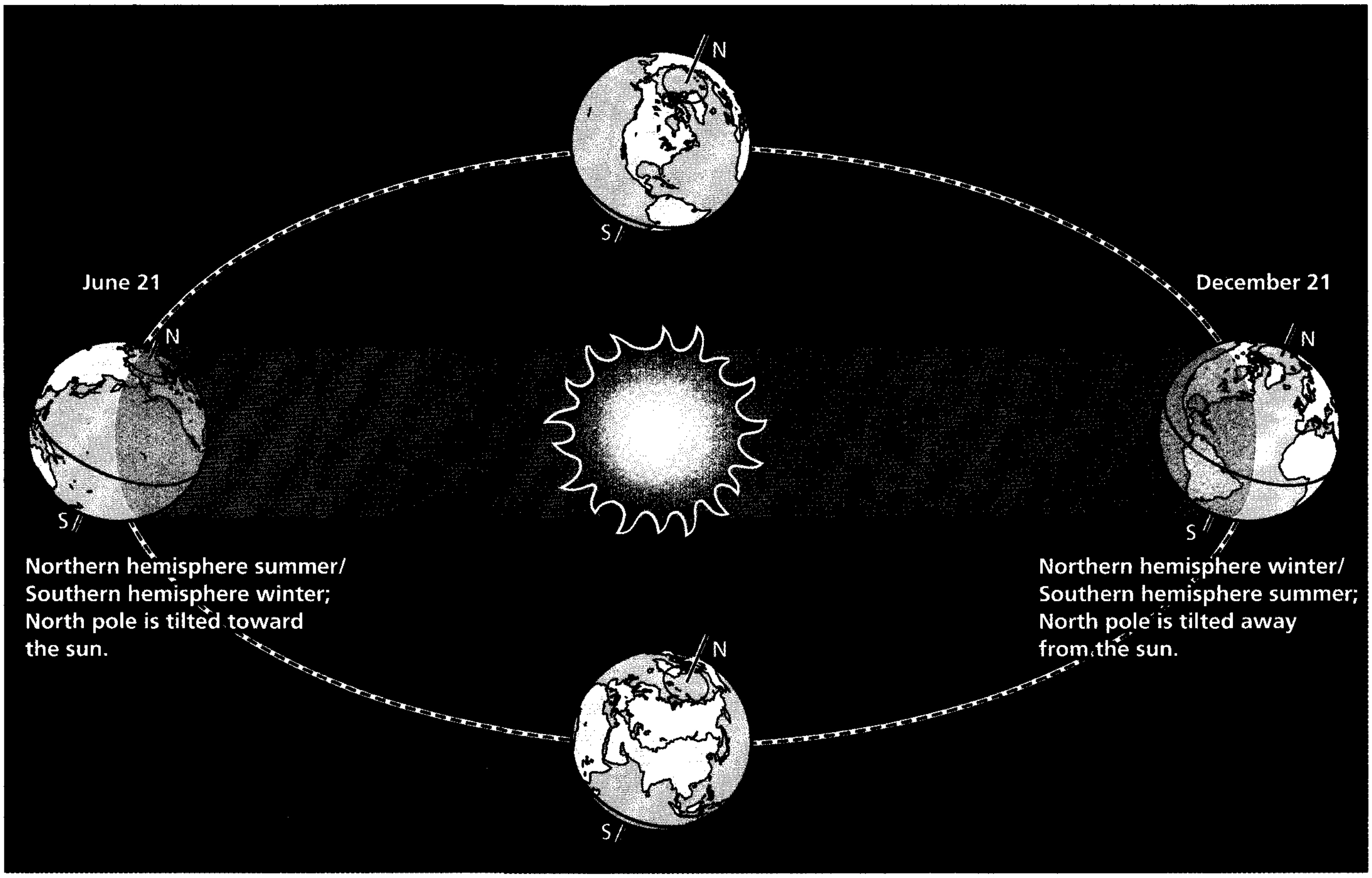


Figure 15.2 Earth's tilt leads to seasonal temperature patterns. Since Earth's axis is 23° from perpendicular to the sun's rays, as Earth orbits the sun during a year, the poles appear to move toward and away from the sun. Solar irradiance is increased at and near a pole when it tilts toward the sun and is decreased when that pole tilts away. The difference in solar energy causes temperatures to vary throughout the year.

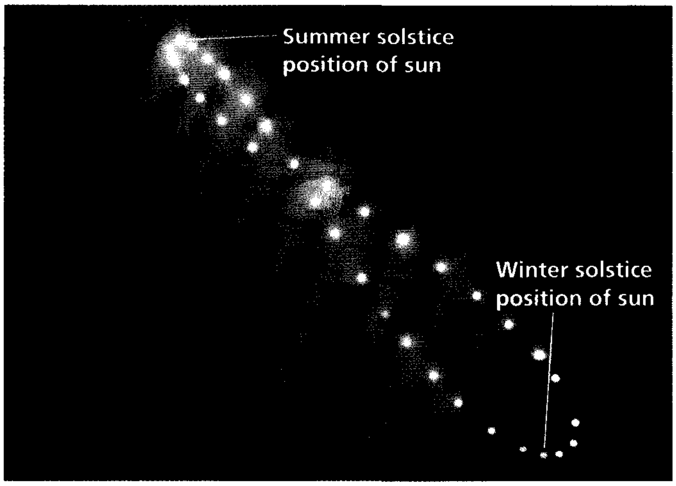


Figure 15.3* *The sun travels across the sky during the year. This image is produced by taking a picture of the sun at the same location and time once each week throughout a year. The sun is highest in the sky at the summer solstice and lowest at the winter solstice.

during the northern winter. The tilt also helps explain why the position of the sunrise changes over the course of a year, moving from south to north as winter turns to summer (Figure 15.3). Note that wintertime in the Northern Hemisphere is summertime in the Southern Hemisphere, and vice versa. Solar irradiance is at its annual maximum in the Northern Hemisphere during the summer **solstice**, the point at which the sun reaches its northern maximum and the North Pole is tilted closest to the sun. In addition, Earth's tilt affects day length, such that the hours of sunlight in the north are greatest at the summer solstice and least at the winter solstice. For example, in Chicago, day length (from sunrise to sunset) is approximately 15 hours at the summer solstice and 9 hours at the winter solstice. The closer a region is to a pole, the greater the variance in day length over the course of a year because the distance traveled by the poles toward and away from the sun is greater than the distances traveled by spots closer to the equator. So while day length in Chicago varies by 6 hours from winter to summer, in Fairbanks, Alaska, it varies by 18 hours from a low of less than 4 hours at the winter solstice to a high of nearly 22 hours at the summer maximum.

Even though the summer solstice is the day of highest solar irradiance in the Northern Hemisphere, it is not the warmest day of the year. Instead, the warmest days of the year are about one month after the solstice. This occurs because Earth stores the light energy it gains from the sun as heat and releases it gradually into the atmosphere. You can think of the solar heat stored in the earth as a bank account. Heat is always dissipating, much like money being withdrawn regularly from a bank account. If money is added to a bank account at the same rate as it is withdrawn, the balance remains the same. Similarly, if heat is added to a location on Earth's surface at the same rate that it is dissipating, the temperature there remains constant. As day length increases, the amount of heat deposited is greater than the amount withdrawn, and the bank account gets larger—that is, the temperature starts to rise. On the longest day of the year, the amount deposited is greatest; but even after that day, the heat deposits are greater than the withdrawals, and the balance (temperature) continues to increase. Similarly, the coldest days of the year are typically a month or so after the winter solstice. In this case, withdrawals remain larger than deposits for several weeks after

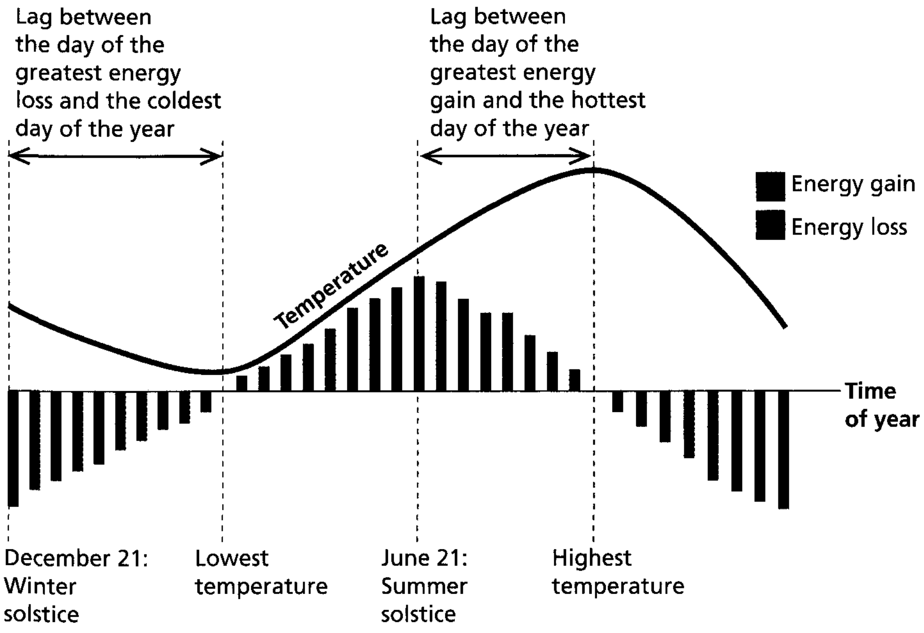


Figure 15.4 Thermal momentum. The longest day of the year—the summer solstice—is not the warmest day of the year at a geographic location because the amount of heat deposited in Earth's "bank" is larger than the amount lost for several weeks following the summer solstice.

the winter solstice (Figure 15.4). The same analogy can help explain why the warmest part of the day is in the middle to late afternoon, even though the solar irradiance is greatest at noon when the sun is directly overhead. In the first few hours of the afternoon, heat gain remains greater than heat loss, increasing temperature.

Because day length changes more dramatically near the poles than near the equator, the bank account balance also changes more dramatically closer to the poles. The amount of balance change explains why seasonal temperature swings are more pronounced closer to the poles than near the equator. The average low temperature for January in Tampa, Florida is 10°C (50°F), and the average high in July is 32°C (90°F), a difference of 22 degrees. On the contrary, the January low in Missoula, Montana is −10°C (14°F), and the July high is 29°C (84°F), a difference of 39 degrees.

Local Factors That Influence Temperature. Solar irradiance is not the only factor that determines average temperature and seasonal variation in a geographic location. Three other characteristics of a location's setting have an effect on its temperatures: (1) altitude, (2) the proximity of a large body of water, and (3) characteristics of the land's surface and vegetation.

Temperature drops as altitude—the height above sea level—increases. Temperature differences due to elevation are dramatic; the summit of Mt. Everest, 8.8 km (5.5 mi) above sea level, averages −27°C (−16°F), while nearby Kathmandu, Nepal, at 1.3 km (4385 feet), averages 18°C (65°F). However, smaller differences in elevation within a region have a converse effect on air temperature. Because cold air is denser than warm air, cold air tends to "drain" to the relatively lowest point on a landscape. Thus valleys and other low spots will often remain colder than nearby hilltops.

Temperatures in areas near oceans, seas, and large lakes are influenced by the thermal properties of water. The temperature of water rises and falls slowly in response to solar irradiation, when compared to the rate of temperature change

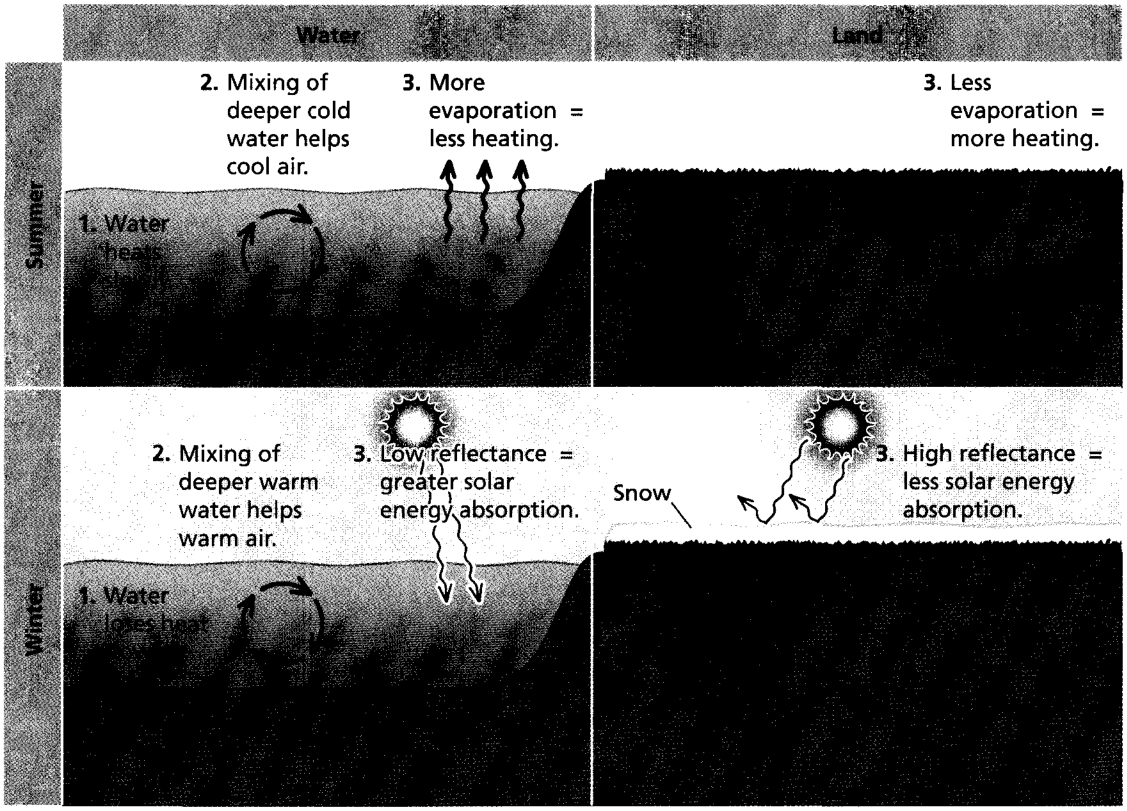


Figure 15.5 The moderating influence of water. Because water heats slowly, large bodies of water increase in temperature more slowly than land regions. Winds blowing across water in spring will cool nearby landmasses. Conversely, water loses heat more slowly than land, so it will send warmer breezes over landmasses in winter.

of land surfaces. Thus, air masses over water are cooler in summer and warmer in winter than are air masses over land (Figure 15.5). Land areas close to large bodies of water experience more moderate temperatures than do regions further inland. Because of this phenomenon, the growing season on the shores of the Niagara peninsula in Canada, bordered by Lake Erie and Lake Ontario, is as much as 30 days longer than the season is further from shore. Another reason that Tampa experiences a much less dramatic temperature range than Missoula is that it is located on the Gulf of Mexico, while Missoula is far from oceans or large lakes.

Oceans also have an effect on local climates because heat is transferred around these large masses of water via currents. Currents that run north and south can carry heat, in the form of warm water, thousands of kilometers around the globe. The warm water heats the air mass above it and thus the nearby landmasses. The Gulf Stream is a current that carries water from the tropical Atlantic Ocean to the shores of northern Europe, producing a much milder climate there than in other areas at the same distance from the equator. The warmth of the Gulf Stream makes Dublin, Ireland as warm as San Francisco, even though Dublin is 1600 km (1000 mi) closer to the North Pole.

The amount of light absorbed or reflected by the land's surface will also influence surrounding air temperature. A surface that reflects most light energy will have a lower nearby air temperature compared to a surface that absorbs most of that energy, heats up, and radiates that heat into the air. Snow reflects more light than a forest does, so air over a snowpack remains cold. The low reflectance of asphalt pavement and most building materials contributes to the urban heat island effect, which is the tendency for

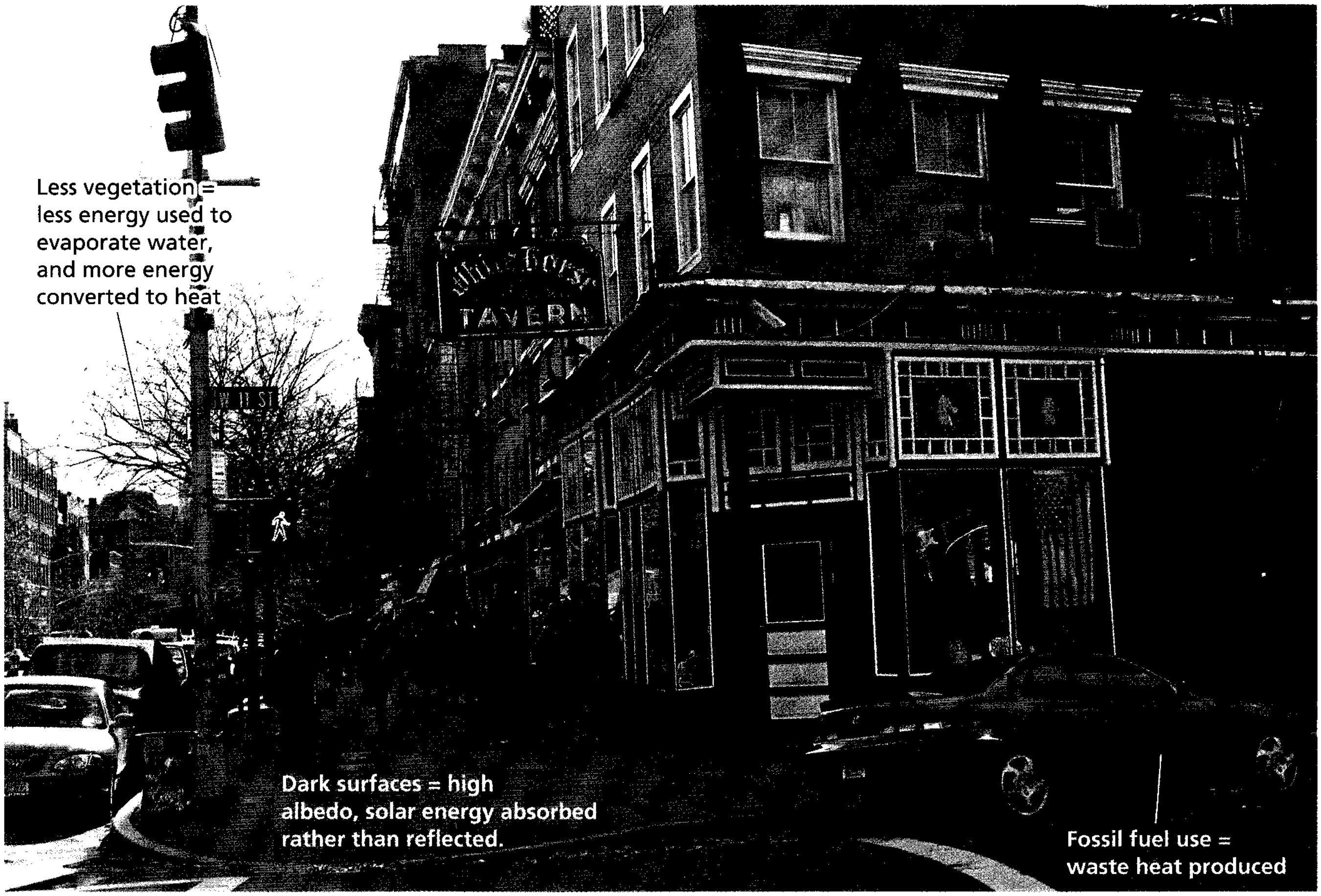


Figure 15.6 Urban heat island. Urban areas are significantly warmer than nearby rural areas for a variety of reasons.

cities to be from 1° to 6°F warmer than the surrounding areas (Figure 15.6). In addition to the heat absorbed by streets and buildings, the increased amount of human activity influences air temperatures in urban areas. Waste heat given off as a result of gas and oil burning or vented from air conditioners can contribute up to one-third of the excess heat in city centers. Cities are also warmer because they contain little vegetation, which tends to reduce air temperature. Much of the solar energy absorbed by plants converts liquid water inside the plant to vapor, which also prevents the energy from being converted to heat.

Precipitation

As with temperature patterns, the amount of rain or snowfall experienced in any location on Earth is a product of both global and local factors.

Distribution of Precipitation on Earth's Surface. Energy from the sun is one of the primary drivers of rain and snowfall patterns on Earth. To understand how sunlight causes rainfall, we must first understand some of the properties of water vapor. Air is composed primarily of nitrogen, oxygen, and water vapor. For water to remain as vapor, evaporation must exceed condensation; that is, the number of water molecules that randomly clump together to form liquid droplets must be less than the number of water molecules that escape from droplets. The rate of evaporation depends on temperature; at high temperatures, evaporation rate is high, and vice versa. Thus when air cools and the rate of evaporation decreases, water molecules clump into larger and larger droplets. When the droplets are large enough,

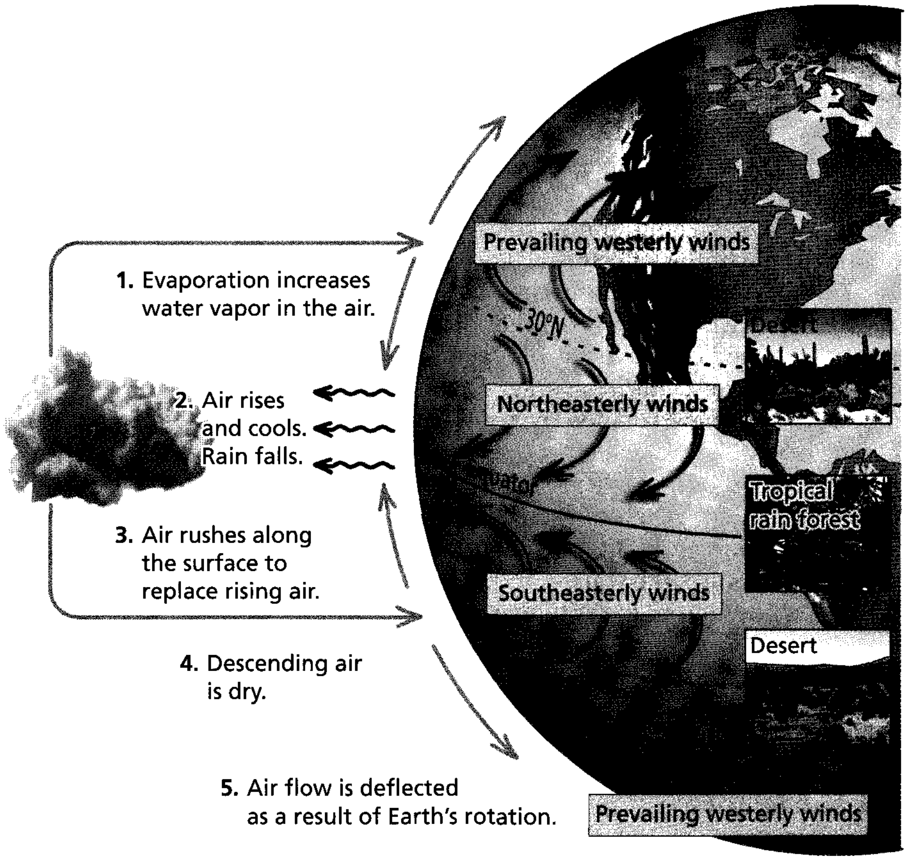


Figure 15.7 Global precipitation and wind patterns. High levels of solar irradiance at the solar equator lead to high levels of evaporation and rainfall. This phenomena drives massive movements of air near the tropics into the temperate zones.

concentrations of them can be seen as clouds. As clouds grow even larger, droplets can become heavy enough to fall as rain. If the temperature inside the cloud is cold enough, droplets will freeze into ice crystals, which may fall as snow.

Rainfall patterns in tropical regions result from the air cycling near Earth's surface to high in the atmosphere and back down, as illustrated in Figure 15.7. Where solar irradiation is highest, at or near the equator, air temperatures rise quickly during the day. Hot air is less dense than cold air. Therefore, air at the equator rises and leaves near Earth's surface an area of low air pressure that is filled by breezes blowing from north and south of this point, which is called the intertropical convergence zone. As the air rises, it cools; water vapor condenses to form clouds and falls to Earth as rain. The now-dry air flows in the upper atmosphere toward the poles, where pressure is lower because of the air flow in the lower atmosphere. The once warm, wet air mass continues to cool and release water and finally drops back to Earth's surface at about 30° north and south latitude. The falling air displaces the ground-level air at these latitudes, and the ground-level air flows toward the poles. As the air mass drops, it is affected by Earth's rotation and thus deflects to the east or west. The movements of these vast air masses create the prevailing winds in various regions of the globe. The pattern of air flow helps explain the band of rain forests near the equator, the great deserts at 30° north and south of the equator, and the tendency for weather patterns in North America to come from the west.

Global rainfall patterns exhibit seasonality as well. The area of maximum solar irradiance travels from 23°N to 23°S over the course of a year due to the 23° tilt in Earth's axis. Therefore, the intertropical convergence zone also moves, creating distinct rainy seasons wherever it is located. Rainy seasons occur in desert areas when the movement of the convergence zone results in prevailing winds that accumulate water vapor from nearby oceans and fall as rain. The monsoon seasons in India and southern Arizona are both associated with these wind shifts.

Local Precipitation Patterns. The amount of precipitation that falls in a given land region is highly dependent on the context of that area—in particular, the land's proximity to a large body of water. Wind blowing across warm water accumulates water vapor that condenses and falls when it reaches a cooler landmass. Communities surrounding the Great Lakes provide a dramatic example of this effect. Because the prevailing winds are from the west, areas immediately to the north and west of these lakes accumulate much less snow than do regions on the southern and eastern sides, which receive winds that have crossed over the warmer lakes. For example, Toronto, on the northwest side of Lake Ontario, averages about 140 cm (55 in) of snow per year, while Syracuse, New York, on the southeast side averages almost twice that—274 cm (108 in).

Precipitation amounts are also affected by the presence of mountains or mountain ranges. When an air mass traveling horizontally approaches a mountain, it follows the landscape's contours and is forced upward. Cooling as it moves upward, the water vapor within it condenses to form clouds, rain, or snow, which falls on the windward side of the mountain. Warming again as it drops down the other side, the dry air mass causes water to evaporate from land on the sheltered or leeward side of the mountain. The dry area that results is often referred to as the mountain's "rain shadow." The Great Basin of North America, encompassing nearly all of Nevada and parts of Utah, Oregon, and California, is a desert because of the rain shadow cast by the Sierra Nevada mountains.

The temperature and rainfall patterns in a geographical region play a major part in determining not only the primary vegetation in that area but also the human activities that are most successful there.

Know Your Bioregion: Describe the climate of the place where you live, including the annual average temperature, average precipitation, average number of sunny days, and names of seasons. What global and local factors influence the climate where you live?

15.2 Terrestrial Biomes

Climate plays the greatest role in determining the physical appearance of the vegetation in a particular geographic area. Plants (and animals) native to a region have adapted, via the process of natural selection, to the water availability and temperatures experienced there. In general, the size of the vegetation is limited by water availability—large trees require large amounts of water. Water availability is obviously a function of total precipitation, but it is also influenced by temperature; frozen water cannot be taken up by plants.

Four basic land **biome** categories, or primary vegetation types, are typically recognized: forest, grassland, desert, and tundra. Each of these biome categories may contain several biome types; for instance, a grassland may be either prairie, steppe, or savanna. The relationship between climate and biome type is illustrated in Figure 15.8. Which of these biomes is your home? And how has the human population changed the environment of your biological neighborhood?

Forests and Shrublands

Forests are vegetation communities dominated by trees and other woody plants. They occupy approximately one-third of Earth's land surface, and when all forest-associated organisms are included, contain about 70% of the

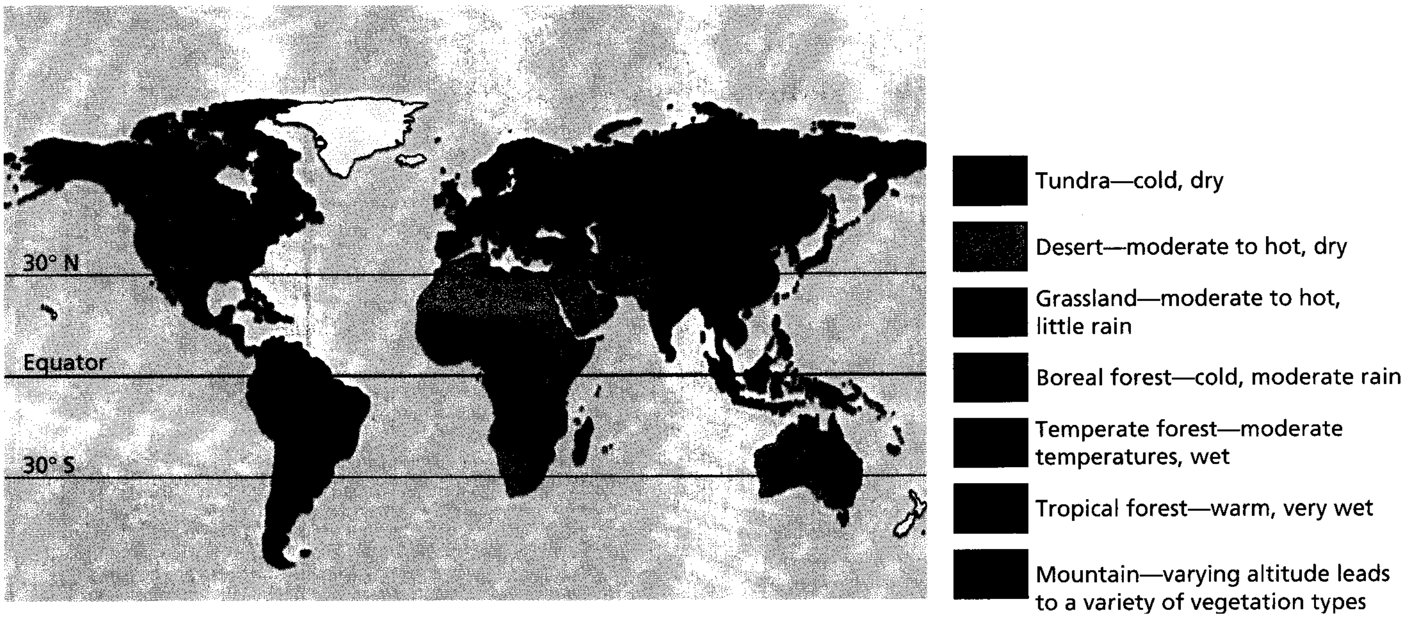


Figure 15.8 The distribution of Earth's biomes. The primary vegetation type in a given area is determined by the region's climate.

biomass, or total weight of living organisms, found on Earth's land surface. Forests are generally categorized into three groups based on their distance from the equator: (1) tropical forests at or near the equator, (2) temperate forests from 23° to 50° north and south of the equator, and (3) boreal forests close to the poles (Figure 15.9).

Tropical Forests. Extensive areas of **tropical forest** were once found throughout Earth's equatorial region—in Central and South America, central Africa, India, southeast Asia, and Indonesia. Tropical forests contain a large amount of biological diversity; one square kilometer may contain as many as 100 different tree species. One hypothesis regarding why tropical forests are so diverse is that these areas receive the largest amount of solar irradiance over the course of a year. Because the energy level is high, adequate populations of many varying species can be supported in a relatively small area. Think of the available energy as analogous to a pizza—the larger the pizza, the greater the number of individuals who can be fed to satisfaction. High energy and water levels also support the growth of very large trees. Because the trees are large and produce many leaves, most of the sunlight is absorbed


(a) Tropical rain forest **(b)** Temperate forest **(c)** Boreal forest

Figure 15.9 Forest biomes. (a) Tropical rain forests are highly diverse and efficient at capturing light before it reaches the ground. (b) Temperate forests contain mostly deciduous trees that drop all of their leaves annually. (c) Boreal forests are often highly uniform, made up of one or two species of coniferous trees.

Figure 15.10 Life in the canopy. Biologists estimate that 70% to 90% of species in the rain forest are found primarily in the trees. This bromeliad, often found more than 60 meters from the forest floor, is vase-shaped as an adaptation to acquire water and nutrients from rainfall rather than soil.

before it hits the ground, meaning that most living organisms in these forests are adapted to survive high in the treetops. Animals are able to fly, glide, or move freely from branch to branch, while small plants are able to obtain nutrients and water even while living on the upper branches of larger plants (Figure 15.10).

With warm temperatures, abundant water, and high energy levels, the process of **decomposition**, the breakdown of waste and dead organisms, is rapid in tropical forests. Dense vegetation quickly reabsorbs the resulting simple nutrients. As a result, few nutrients are stored in the soils of tropical forests. When vegetation is cleared and burned in preparation for agricultural crops in these areas, the ash-fertilized soils can support crop growth for only 4 to 5 years. Among human populations in tropical forest areas, this slash-and-burn (or swidden) agricultural system is common. Once soils are depleted of nutrients, the plots are abandoned, and a new field is cleared using the same method. The history of human settlement and agriculture in tropical rain forests indicates that tropical forests can indefinitely support swidden agriculture if the population is small enough that abandoned plots have several decades to recover. However, increasing human population levels in tropical countries may be too large to allow for adequate recovery before the land is needed again, and road building into areas with previously small human populations has forever changed the nature of these interior forests—from ancient and mostly undisturbed to swidden fields (Figure 15.11).

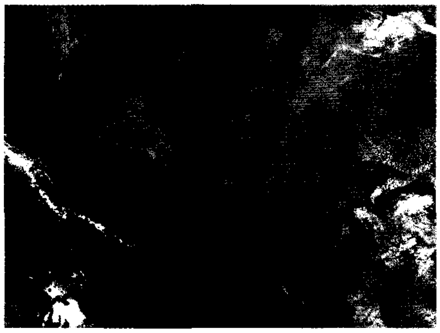


Figure 15.11 Clearing for agriculture. The red dots trailing white smudges of smoke in this satellite image of the Amazonian rain forest in Brazil are active fires, set by newly arrived farmers in order to prepare the land for farming. The amount of tropical forest land converted to agriculture is greater now than at any other time in human history.

Temperate Forests. Some areas of tropical forest, especially those further from the equator, may demonstrate seasonal changes between annual wet and dry periods. But most people associate major seasonal change with forests in temperate areas, where winter temperatures can drop well below the freezing point of water. Large areas of **temperate forest** appear in eastern North America, and only remnants of these forests remain in western and central Europe and eastern China. In temperate forests, water is abundant enough throughout the year to support the growth of large trees, but cold temperatures during the winter limit photosynthesis and freeze water in the soil. Trees with broad leaves can grow faster than narrow-leaved trees, so they have an advantage in the summer. However, broad leaves allow tremendous amounts of water to evaporate from a plant, leading to potentially fatal dehydration when water supplies are limited. To balance these two seasonal challenges, most trees in temperate forests have evolved a **deciduous** habit, meaning that they drop their leaves every autumn. In preparation for shedding its leaves, a deciduous tree reabsorbs their chlorophyll, the green pigment essential for photosynthesis. The colorful fall leaves that grace eastern North America in September and October result from secondary photosynthetic pigments and sugars that are left behind.

The short time lag between the onset of warm temperatures and the re-leafing of deciduous trees provides an opportunity for plants on the temperate forest floor to receive full sunlight. Spring in these forests triggers the blooming of wildflowers that flower, fruit, and produce seeds quickly before losing the competition for light and water to their towering companions (Figure 15.12). The lighter leaves of deciduous trees allow more sunlight through than do their tropical forest equivalents. Therefore, temperate forests typically have a shrub layer that may be missing in the tropics. Also, animals in temperate forests are more evenly distributed throughout the forest, not primarily concentrated in the treetops.

Figure 15.12 Springtime in a temperate forest. The time between soil thawing and the production of leaves by the canopy trees is a window of opportunity for plants growing on the temperate forest floor. They are adapted to take advantage of this limited sunlight by emerging from the soil, flowering, and producing fruit rapidly.

Since their soils are relatively easy to turn over and are rich in nutrients, nearly all of the forested lands in the eastern United States were converted to farmland within 100 years of the American Revolution. However, in the late nineteenth and early twentieth centuries, farms in the eastern United States were abandoned as inexpensive transportation networks made produce grown elsewhere cheaper for consumers and more reliable for suppliers. Now, many of these abandoned farms have grown back into forest. However, these second-growth forest sites are once again threatened—this time by expanding urban development. The World Wildlife Fund estimates that worldwide, only 5% of temperate deciduous forests remain relatively untouched by humans.

Boreal Forests. The largest biome on Earth is the **boreal forest**, covering vast expanses of northern North America, northern Europe and Asia, and high-altitude areas in the western United States. Unlike tropical and temperate forests, which are dominated by trees from the phylum of flowering plants called angiosperms, **coniferous** trees from the phylum of plants that produce seed cones (gymnosperms) dominate boreal forests (Figure 15.13). In fact, boreal forests are among the only land areas where flowering plants are not the dominant vegetation type. Climate conditions for boreal forests include

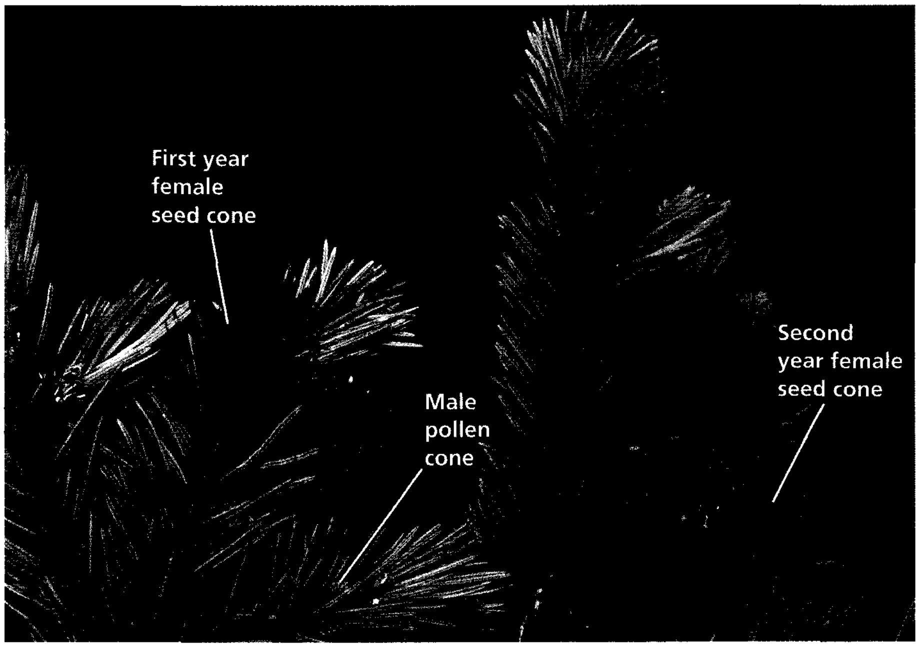


Figure 15.13 Coniferous trees. Cone-bearing plants produce sperm and eggs on cones instead of in flowers. Sperm is packaged in pollen grains, which are typically carried by wind to a female cone that contains the egg. The fertilized egg and its surrounding tissue develops into a seed inside the cone.

very cold, long, and often snowy winters, and short, moist summers. The dominant conifers in these forests are evergreens, meaning that like many tropical forest trees, they maintain their leaves throughout the year. However, coniferous tree leaves are needle shaped and coated with a thick, waxy coat—both adaptations to reduce water loss when water freezes in the soil. The evergreen habit likely explains conifers' dominance over flowering trees in boreal forests—the growing season is so short that an evergreen's ability to begin photosynthesizing as soon as water is available in spring gives it a great advantage over a faster-growing but slower-to-start deciduous tree.

Since they occupy regions with such climate challenges, boreal forests tend to be lightly populated by humans. These areas represent some of the "wildest" landscapes on Earth—home to moose, wolves, bobcat, beaver, and a surprising diversity of summer-resident birds (Figure 15.14). Trees in these landscapes are valuable for both building materials and paper products, and logging in the boreal forest is extensive. There are increasing concerns that the boreal forest in North America is being cut at rates faster than it can be replaced. Certainly, as logging operations push deeper into previously untouched areas, this biome is changing rapidly, putting the iconic wild species of the boreal forest at increased risk of becoming endangered or extinct.

Figure 15.14 Diversity in the boreal forest. Plant diversity in the boreal forest is relatively low due to difficult winter conditions, but bird diversity during summer is surprisingly high. This Blackburnian warbler is one of many bird species breeding in the boreal forest during summer, when a combination of abundant sunshine and few permanent resident birds provides enormous numbers of available insects to feed their growing offspring.

Chaparral. One major biome is dominated by woody plants but is not a forest. This landscape is known as **chaparral**, and its vegetation consists mostly of spiny evergreen shrubs (Figure 15.15). Chaparral is found extensively in areas surrounding the Mediterranean Sea and in smaller patches in southern California, South Africa, and southwest Australia. Long, dry summers and frequent fires maintain the shrubby nature of chaparral. In fact, chaparral vegetation is uniquely adapted to fire. Natural selection in this climate favored species that respond well to fire (Essay 15.1). Several species have seeds that will germinate only after experiencing high temperatures. Many **perennial**, or long-lived, chaparral plants have extensive root systems that quickly resprout after aboveground parts are damaged. Chaparral will grow into temperate forest when fire is suppressed. As a result, natural selection has favored chaparral shrubs that actually encourage fire—such as rosemary, oregano, and thyme, which contain fragrant oils that are also highly flammable.

Fire can be an important contributor to the structure and function of many biomes. In southern California, the flammability of chaparral vegetation has come directly into conflict with rapid population growth and urbanization. In fall 2003, this area experienced its most extensive and expensive fire season ever as 750,000 acres of shrubland and surrounding forest burned—consuming over 3200 buildings and killing 17 people in San Diego County alone. In response to this disaster, recommendations by a state task force have called for a policy of putting wildfire protection ahead of protection of wildlife and wildlife habitat.

Figure 15.15 Chaparral. Much of the scrubby landscape of southern California is made up of this biome type.

Essay 15.1 Wildfire!

Since 1944, Smokey Bear's message has been the same: "Only YOU can prevent forest fires." At that time in history, forest fires seemed only to be destructive, sinister forces that could cause widespread death and destruction of people, buildings, and wildlife. In fact, in 1905, the U.S. Forest Service's official policy became total fire suppression—all wild land fires would attempt to be snuffed out, and prevention, as symbolized by Smokey, became everyone's business.

Unfortunately, Forest Service biologists of the time had little understanding of the role of periodic fire in maintaining healthy biological communities in various regions of the United States. Six vegetative communities in North America are fire-adapted, meaning that the species they contain have evolved strategies for surviving periodic fires. In fact, in the absence of fire, these communities may change dramatically. Fire-dependent systems include chaparral, prairies, and pine-dominated habitats in the Great Lakes, Southeast, Northwest, and Rocky Mountains.

Adaptations to fire include thick bark (Ponderosa Pine bark is 4 inches thick at the soil's surface), the ability to quickly resprout from extensive underground roots and stems (as in the case of prairie grasses and fireweed), cones that require intense heat in order to release seeds (such as Jack Pine), and seeds that require exposure to smoke in order to germinate (several flowering herbs in the western United States, for example). In fire-adapted systems, periodic fires help to increase overall plant growth by converting downed woody material into ash that fertilizes the soil and also serves to increase diversity by creating patches of different ages within larger regions.

After a fire, communities go through **succession**, the progressive replacement of different suites of species over time. Generally, the first colonizers of vacant habitat are fast-growing species that produce abundant, easily dispersed seeds. These pioneers are replaced by plants that grow more slowly but are better competitors for light and nutrients. Eventually, a habitat patch is dominated by a set of species—called the **climax community**—that cannot be displaced by other species without another environmental disturbance. For instance, in boreal forests, the fireweed and lupine that dominate immediately after the fire are replaced by deciduous aspen and birch forest, which is then replaced by coniferous spruce and fir forest (Figure E15.1). Without periodic fires, the boreal forest system would consist solely of the climax community and thus be significantly less diverse.

The century-long policy of fire suppression has changed fire-adapted ecosystems dramatically. Now many forests contain large amounts of "fuel" in the form of dead vegetation, and fires that start in these forests quickly become intense conflagrations that can cover thousands of acres, killing trees and other organisms that are adapted to smaller, cooler fires. The Forest Service now struggles with the consequences of their policy of fire suppression, not only fighting more dangerous, destructive fires, but also fighting the perception that they fostered for many years—that forest fires are only bad.

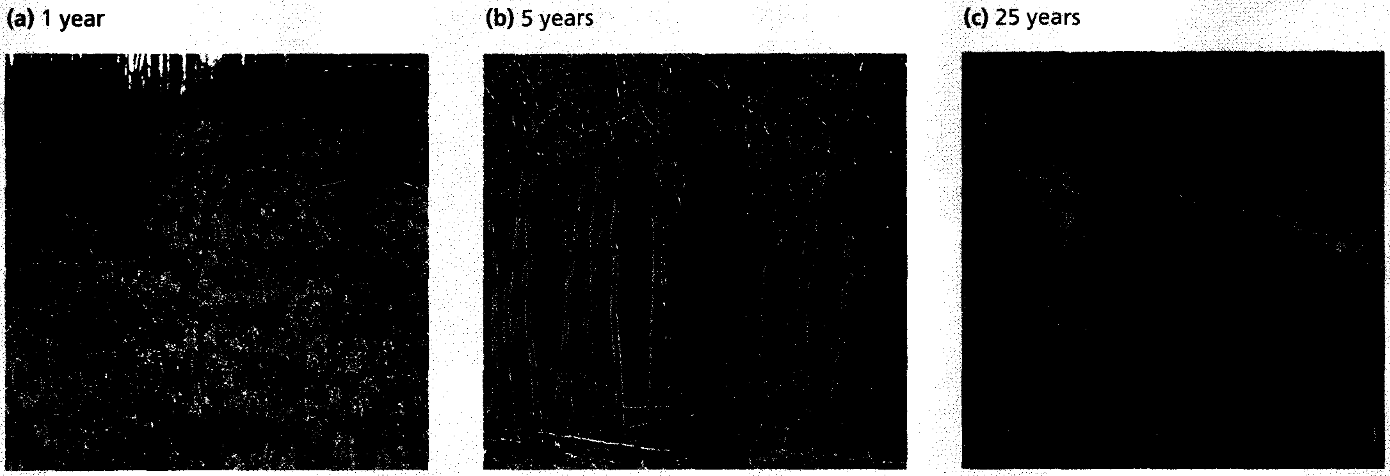

(a) 1 year **(b)** 5 years **(c)** 25 years

Figure E15.1 Succession after fire in a boreal forest.

Because of this policy, and in combination with the long-term human modification of chaparral in the Mediterranean basin, this unique biome is one of the most threatened on the planet.

Grasslands

Grasslands are regions dominated by nonwoody grasses; they contain few or no shrubs or trees. These biomes occupy geographic regions where precipitation is too limited to support woody plants. Grasslands can be further categorized into tropical and temperate categories.

Figure 15.16 Savanna. Grasslands in tropical areas can support huge herds of grass-eating mammals—and their associated predators.

Tropical grasslands are known as **savannas** and are characterized by the presence of scattered individual trees (Figure 15.16). Savanna covers about half of the African continent as well as large areas of India, South America, and Australia. Savannas are maintained by periodic fires or clearing. In regions where wet and dry seasons are distinct, yearly grass fires during the dry season kill off woody plants; in regions where elephants and other large grazing animals are present, the damage these animals do to trees helps to maintain the grass expanse (Figure 15.17). Because grazing animals eat the tops of plants, natural selection in these environments has favored plants, like grasses, that keep their growing tip at or below ground level. Because grass grows from its base, grazing (or mowing) is equivalent to a haircut—trimming back but not destroying. Woody plants grow from the tips, so intense grazing can destroy these plants.

Grass leaves are very fibrous and thus difficult to digest. Grazers that could obtain more nutrients from these plants were favored by natural selection in grassland environments. The most common adaptation is a relationship with bacteria that live in a specialized chamber of the grazer's digestive system and partially digest the grass so that more nutrients are available to the animal. Although grazing mammals are characteristic of savannas, in some savanna areas where domesticated grazers such as cattle have been introduced, the landscape has been transformed from grassland to bare, sandy soil. In the Sahel region of central Africa, hundreds of acres of savanna are lost each year due to overgrazing—that is, allowing more livestock on the grassland than can be sustained.

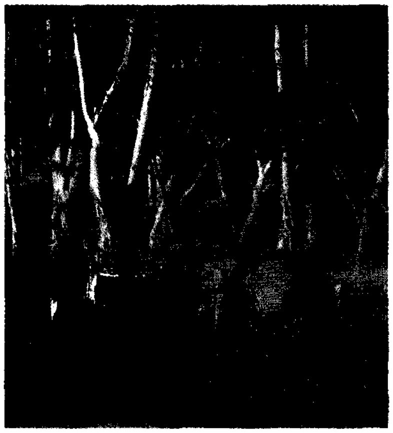


Figure 15.17 Savanna maintenance. Some of the grasslands in Africa are maintained by the enormous appetites and destructive power of elephants. Elephants severely prune acacia trees when feeding on them, keeping the trees' size relatively small; they actively destroy thorny myrrh bushes that they do not eat, which provides additional habitat for grass to grow.

Temperate grassland biomes include tallgrass **prairies** and shortgrass **steppes**. Generally, the height of the vegetation corresponds to the precipitation—greater precipitation can support taller grasses. Prairies and steppes are found in central North America, central Asia, parts of Australia, and southern South America. These landscapes are generally flat to slightly rolling and contain no trees. In the cooler temperate regions, decomposition is relatively slow, and the soil of prairies and steppes is rich with the partially decayed roots of grasses and small nonwoody plants (Figure 15.18). These soils provide an excellent base for agriculture, and most native prairies and steppes have been plowed and replanted to crops. In North America, less than 1% of native prairie remains. Where precipitation is too low to support plant crops, cattle may be grazed or groundwater pumped to irrigate "dry land" crops such as wheat.

Desert

Where rainfall is less than 50 centimeters (20 inches) per year, the biome is called **desert**. This biome can be found throughout the world, but the world's great deserts include the Sahara in northern Africa, the Gobi of central Asia, and the deserts of the Middle East, central Australia, and the southwestern United States. Most of these deserts are close to 30° north or 30° south of the equator, where the air masses that were "wrung" of water in the rain-forest regions around the equator fall back to Earth's surface as hot and dry winds. Although the image of a desert is often hot and sandy, some deserts can be quite cold; most deserts have vegetation, although it can be sparse.

Plants and animals in desert regions have evolutionary adaptations to retain and conserve water. For example, plants are often thickly coated with waxes to reduce evaporation, contain photosynthetic adaptations that reduce water loss through leaf pores, and may be protected from predators by spines and poisonous compounds (Figure 15.19). Deserts are also home to many fast-growing **annual** herbs—flowering plants that complete their entire life cycle from seed to seed in a single season. In deserts, the wet season, the time during which a shallow-rooted annual plant can survive, is quite short; many desert-adapted, annual plants can germinate, flower, and produce seeds in a matter of 2 or 3 weeks. The seeds they produce are hardy and adapted to survive in the hot, dry soil for many years until the correct rain conditions return. Some animals in these dry environments have physiological adaptations that allow them to survive with little water intake. The most amazing of these animals are the various species of kangaroo rat, which apparently never consume water directly. Instead, they conserve water produced during the chemical reactions of metabolism and have kidneys that produce urine 4 times more concentrated than our own.

The sunny, warm, and dry climate of the deserts in Arizona and New Mexico is appealing to people; this region has the greatest rate of human population growth in the United States. The increasing population is putting stress on water supplies in these dry states, threatening the ability to support the water needs of cities and agricultural production as well as depleting water sources for native animals. The Colorado River is so extensively used that often it cannot sustain a flow through its historic outlet at the Gulf of California. Recent surveys indicate that of the species once found in the delta region of the Colorado River, which a century ago was one of the most biologically productive areas in North America, up to 95% are now gone.

Figure 15.18 A prairie in bloom. Although the dominant plants on prairies are grasses, some of the less numerous plants produce large, colorful flowers. This is a midwestern prairie in late summer.

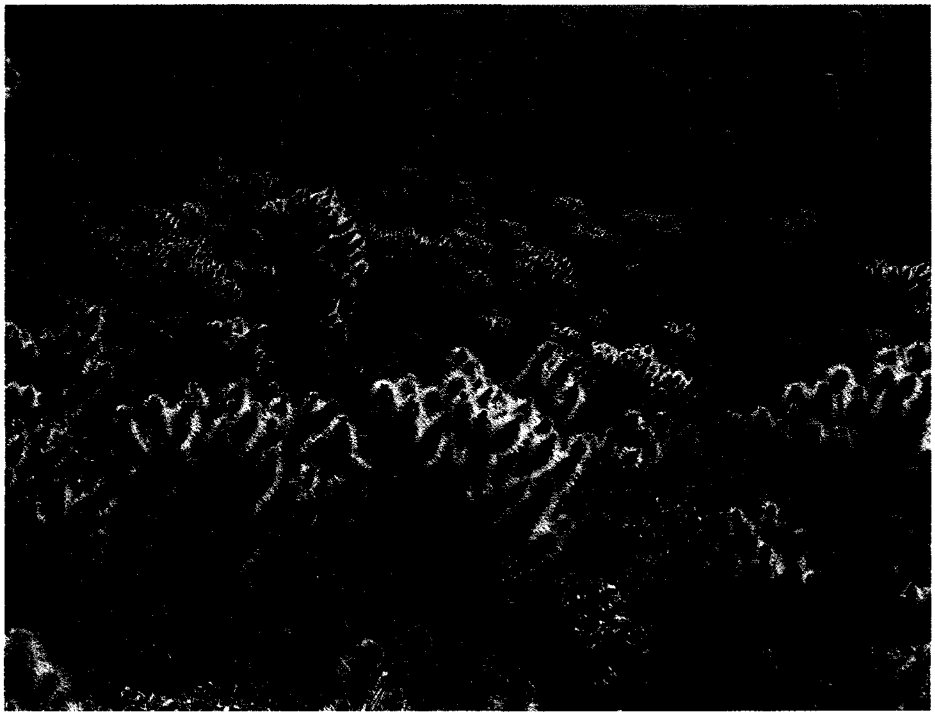


Figure 15.19 Adaptations to constant drought. Desert plants have several strategies for conserving water: thick, whitish, and waxy coatings to reflect light and reduce evaporation; a column-like form to reduce exposure to the high-intensity sun during the middle of the day; the ability to store water in their stems; and the modification of leaves to spines that discourage predators from accessing their water or damaging their protective surface.

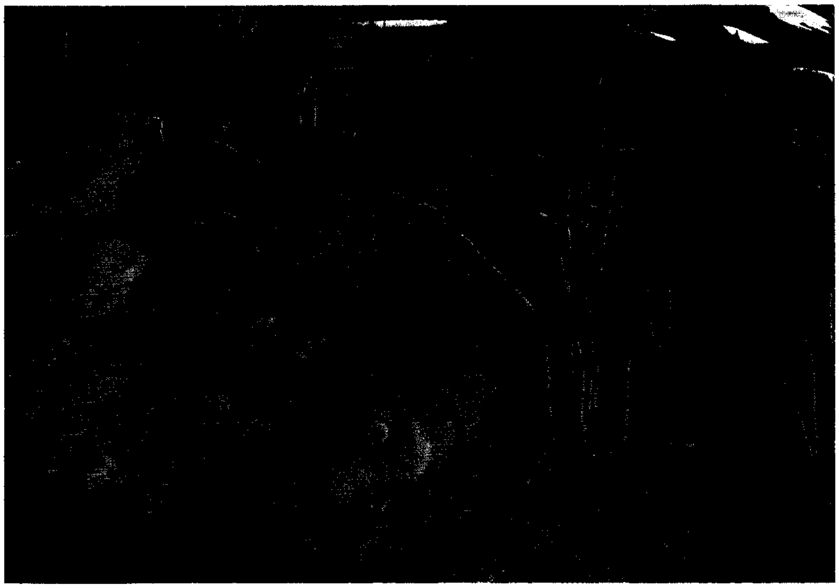


Figure 15.20 Tundra. A marmot feeds on lush green tundra vegetation in Alaska. The short growing season and the year-round chance of below-freezing temperatures limit the vegetation of the tundra to ground-hugging plants.

Tundra

The biome type where temperatures are coldest—close to Earth's poles and at high altitudes—is known as **tundra** (Figure 15.20). Here plant growth can be sustained for only 50 to 60 days during the year, when temperatures are high enough to melt ice in the soil. High temperatures are not sustained long enough to melt all of the soil's ice. Therefore, places like the arctic tundra near the North Pole are underlaid by **permafrost**, icy blocks of gravel and finer soil material. The permafrost layer impedes water drainage, and soils above permafrost are often boggy and saturated. Plants in tundra regions are low to the ground and adapted to windswept expanses and freezing temperatures. For example, tundra plants often grow in multispecies "cushions" where all individuals are the same height, obtaining shelter from and providing shelter for each other. Surprisingly, this low vegetation supports a large and diverse community of grazing mammals, such as caribou and musk oxen, and their predators, such as wolves. Animals in tundra regions have evolved to survive long winters with adaptations, such as storing fat and producing extra fur or feathers. Other animals, such as ground squirrels, have adapted by evolving a behavior called hibernation; they enter a sleeplike stage during which their metabolism is extremely low in order to maximize energy conservation. Grizzly bears and female polar bears also spend much of the coldest months in a deep sleep; although this is not true hibernation, these bears are so lethargic that females give birth in this state without fully awakening. Other animals survive by migrating south to avoid the hardships of a long, frigid winter. Hundreds of millions of birds, migrating from the arctic tundra or other polar regions toward the equator and back again, take part in one of the great annual dramas of life on Earth (Figure 15.21).

Tundra is very lightly settled by humans, but it is threatened by our dependence on fossil fuels—oil, natural gas, and coal that formed from the remains of ancient plants. Some of the largest remaining untapped oil deposits are found in tundra regions, including northern Alaska, Canada, and Siberia. However, use of fossil fuels appears to be causing Earth to warm (see Chapter 4), and global warming has been greatest at the poles, where tundra is predominant. Winters in Alaska have warmed by 2° to 3°C (4°–6°F), whereas elsewhere they have warmed by about 1°C. As climate conditions change, areas that were once tundra have begun to support shrub and tree growth and are changing into boreal forest.

Know Your Bioregion: Describe the native vegetation of the place where you live. How much native vegetation remains? What ecological factors (climate, fire, etc.) have influenced the native vegetation type?

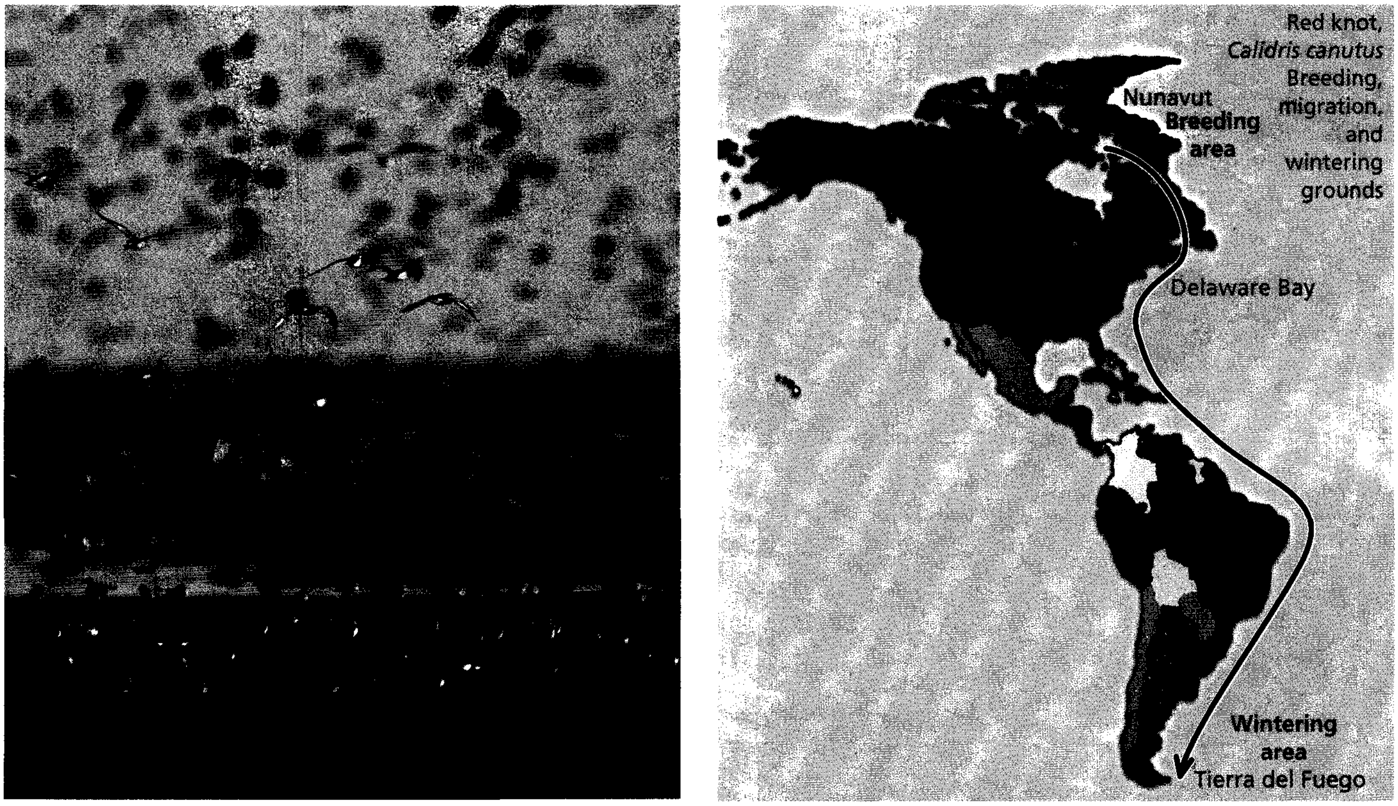


Figure 15.21 Migration. Birds that breed in the Arctic, such as these red knots massed on the beach at Delaware Bay undertake a fatiguing and perilous journey in order to take advantage of the abundant daylight and insect life available during summer on the tundra.

15.3 Aquatic Biomes

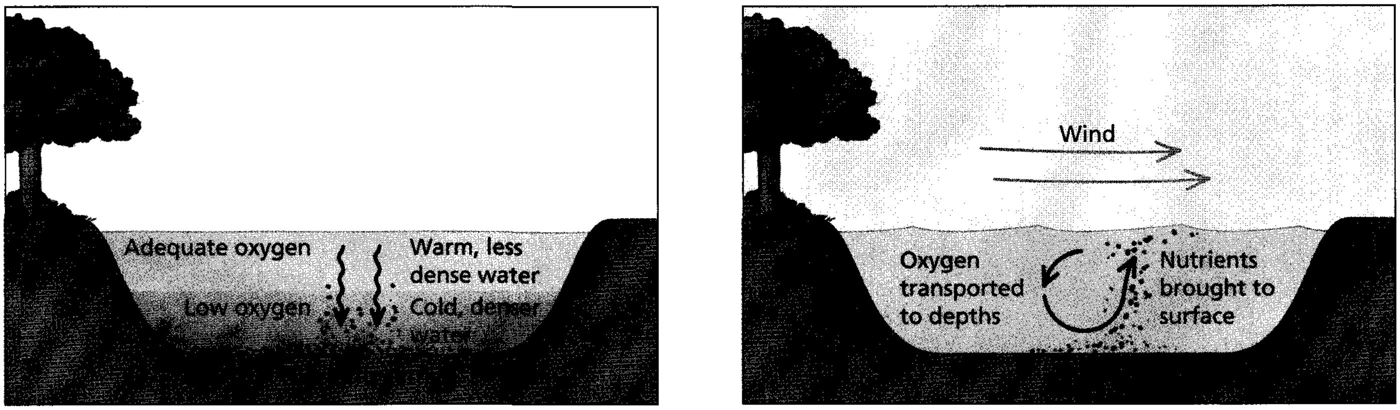
Nearly all human beings live on Earth's land surface; but most people also live near a major body of water and are both influenced by, and have an influence on, these **aquatic** systems. Aquatic biomes are typically classified as either freshwater or saltwater. As you read this section of the chapter, consider the water bodies that affect you most and how you affect them.

Freshwater

Freshwater is characterized as having a low concentration of salts—typically less than 1% of total volume. Scientists usually describe three types of freshwater biomes: lakes and ponds, rivers and streams, and wetlands.

Lakes and Ponds. Bodies of water that are inland, meaning surrounded by land surface, are known as **lakes** or **ponds**. Typically, ponds are smaller than lakes, although there is no set guideline for the amount of surface area required for a body of water to reach "lake" status. Some ponds, however, are small enough that they dry up seasonally. In temperate regions, these are called vernal ponds, from the Latin word *vernalis*, meaning "of the springtime." Vernal ponds are often crucial to the reproductive success of frogs and salamanders as well as a variety of insects that spend part of their lives in water.

The aquatic environment of lakes and ponds can be divided into different zones: the surface and shore areas, which are typically warmer, brighter, and thus full of living organisms; and the deepwater areas, which are dark, low in oxygen, cold, and home to mostly decomposers. The biological productivity of lakes in temperate areas is increased by seasonal turnovers—times of the year when changes in air temperature and steady winds lead to water mixing,



(a) Lake in summer

(b) Lake in fall and spring

(c) Algal bloom in lake

Figure 15.22 Nutrients in lakes. (a) A lake is stable during the summer, and oxygen levels in deeper regions diminish as nutrient levels near the surface decline. (b) Nutrients and oxygen are mixed throughout a lake during fall and spring "turnover," providing the raw materials that enable photosynthetic production. (c) Large inputs of nutrients during summer may occur when nearby agricultural and landscaping activity fertilizes a lake. High nutrient levels lead to "blooms" of algae growth, severe oxygen depletion, and a risk of fish kills.

redistributing nutrients that had settled on the bottom of the lake and bringing fresh oxygen to deeper water (Figure 15.22).

Nutrients applied to agricultural lands and residential lawns near lakes and ponds can also increase their algae populations as the nutrients leach into the water; ironically, too many nutrients added in this way can lead to the "death" of these water bodies. Their degradation occurs because large populations of algae (and the microorganisms that feed on them) can lead to low oxygen levels and thus the death of fish.

Rivers and Streams. **Rivers** and **streams** are flowing water moving in one direction. These waterways can be divided into zones along their lengths. At the headwaters of a river—often a lake, an underground spring, or near a melting snowpack—the water is clear, cold, and fast-flowing; it is thus high in oxygen, providing an ideal habitat for cold-water fish such as trout (Figure 15.23a). Near the middle reaches of a river, the width typically increases. Also increasing is the diversity of fish, reptile, amphibian, and insect species that the river supports because the warming water provides a better habitat for photosynthetic plants and algae. At the mouth of a river, where it flows into another body of water, the speed of water flow is often slower, and the amount of sediment—soil and other particulates carried in the water—is high. High levels of sediment reduce the amount of light in the water and therefore the diversity of photosynthesizers that survive there. Oxygen levels are also typically lower near the mouth since the activities of decomposers increase relative to photosynthesis. Many of the fish

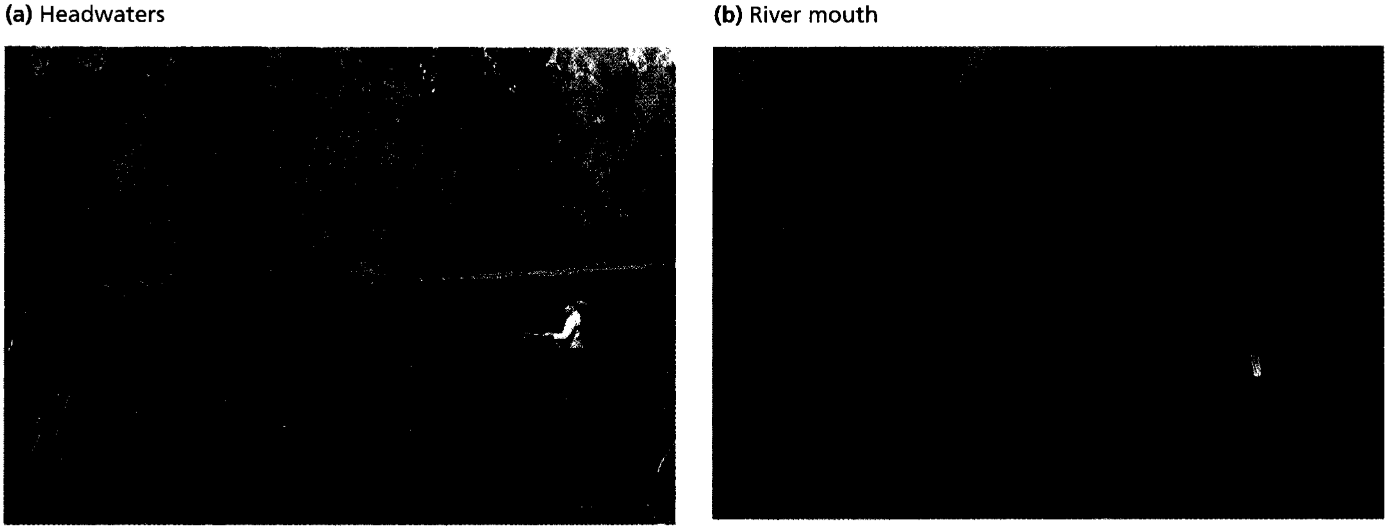


Figure 15.23 **River habitats.** (a) The Colorado River is fed by numerous headwater streams that originate in the mountain snowpacks of Colorado and Wyoming. The river here is cold, fast flowing, and rich in oxygen. (b) With sluggish water flow, warmer temperatures, and high nutrient levels, the mouth of a river is a very different habitat.

found at the mouth of a river are bottom-feeders such as carp and catfish, which eat the dead organic matter that flowing water has picked up along its way (Figure 15.23b).

Rivers and streams are threatened by the same pollutants that damage lakes. But their habitats also face wholesale destruction with the development of dams and channels—dams to provide hydropower or reservoirs for cooling fossil-fuel-powered, electricity-generating plants; and channels to simplify and expedite boat traffic.

Wetlands. Areas of standing water that support emergent, or above-water, aquatic plants are called **wetlands** (Figure 15.24). In numbers of species supported, wetlands are comparable to tropical rain forests. The high biological productivity of wetlands results from the high nutrient levels found at these interfaces between the aquatic and land environments. Besides their importance as biological factories, wetlands provide health and safety benefits by slowing down the flow of water. Slower water flows reduce the likelihood of flooding and allow sediments and pollutants to settle before the water flows into lakes or rivers.

Since the European settlement of the continental United States, over 50% of wetlands have been filled, drained, or otherwise degraded. Although extensive efforts by environmental organizations over the past 25 years have led to legislation that has greatly slowed the rate of wetland loss in the United States, about 58,000 acres are still destroyed every year.

Saltwater

About 75% of Earth's surface is covered with saltwater, or **marine**, biomes. Marine biomes can be categorized into three types: oceans, coral reefs, and estuaries.

Oceans. Like lakes, **oceans** can be divided into distinct zones. Areas near the surface with abundant light support the largest number of phytoplankton—microscopic algae suspended in the water—and thus provide food for most organisms that inhabit the ocean. Deeper, darker areas are colder, have less oxygen, and contain mostly decomposers, which filter dead organic matter that drops from the surface.

Unlike lakes, oceans experience tides—regular fluctuations in water level caused by the gravitational pull of the moon on these large bodies of water. As a result of tides, oceans contain unique habitats known as **intertidal zones**, which are underwater during high tide and exposed to air during low tide. Organisms

Figure 15.24 **Wetlands.** This dragonfly rests on a cattail emerging from a lakeside marsh. Wetlands provide an important habitat for a wide variety of creatures.

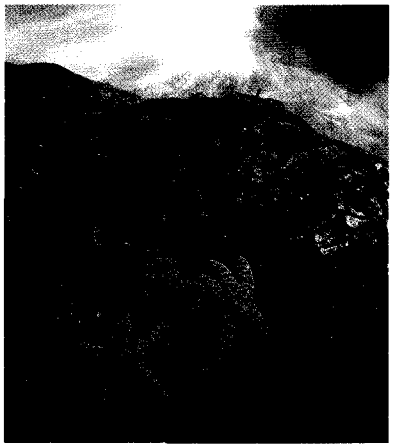


Figure 15.25 Intertidal zones. Tatoosh Island off the coast of Washington state is the site of the longest-running ecological research program in the United States. Robert Paine, the scientist who began studying this area in 1960, has used this site as a natural laboratory to study ecological interactions among the organisms living in the island's tidal pools.

in intertidal zones must be able to survive the daily fluctuations and rough wave action they experience. Adaptations such as strong anchoring structures, burrow building, and water-retaining, gelatinous outer coatings allow animals and seaweeds to take advantage of the high-nutrient environment found along the shore. Because they experience such dramatic environmental changes and are so rich in nutrients, intertidal zones have proven to be excellent habitats for studies of important ecological interactions (Figure 15.25).

Oceans also contain a habitat known as the abyssal plain; in very deep water where sunlight never penetrates, temperatures can be quite cold, and the weight of the water above creates enormous pressure. Once thought to be lifeless because of these conditions, the abyssal plain is surprisingly rich in life, supported primarily by the nutrients that rain down from the upper layers of the ocean. Animals living in these dark recesses are often blind, with highly developed senses of touch that can detect the tiniest movements of potential food items. In this case, natural selection favored animals that had devoted more of their nervous system to senses that are useful in the dark, relative to animals that still committed their resources to producing eyes. In the 1970s, researchers studying the deep ocean discovered an entire ecosystem supported by bacteria that use hydrogen sulfide escaping from underwater volcanic vents as an energy source. Animals in this ecosystem either use the bacteria as a food source directly or have evolved a mutualistic relationship with them, providing living space for the bacteria while benefiting from the bacteria's metabolism. The abyssal plain represents the last major unexplored frontier on Earth.

Photosynthetic organisms in the open oceans function as Earth's lungs, taking in carbon dioxide and releasing enormous amounts of oxygen (the opposite of our lungs, which take in this oxygen and release carbon dioxide). In fact, about 50% of the oxygen in Earth's atmosphere is generated by single-celled photosynthetic plankton in the oceans. Photosynthetic plankton serve as the base of a food chain, providing energy to microscopic animals called zooplankton, which in turn feed fish, sea turtles, and even large marine mammals such as blue whales. These predators provide a source of food for yet another group of predators, including sharks and other predatory fish, as well as ocean-dwelling birds such as albatross. Oceans also generate most of Earth's freshwater. The water molecules evaporating from their surface condense and fall on adjacent landmasses as rain and snow.

Coral Reefs. **Coral reefs** are unique biomes in that the structure of the habitat is composed of the skeletons of the dominant organism in the habitat: coral animals. Coral animals are very simple in structure but have a unique lifestyle—they filter dead organic material from the water and harbor photosynthetic algae inside their bodies. Up to 90% of a coral's nutrition is provided by the algae, which receives as its benefit a protected site for photosynthesis and easy access to nutrients and carbon dioxide from the coral animal. Reef-building coral live in large colonies, and each individual coral secretes a limestone skeleton that protects it from other animals and from wave action (Figure 15.26). Coral reefs are made up of the accumulations of billions of these skeletons, as well as the remains of other organisms that use the reef as a home.

Coral reefs are found throughout the tropics, in warm and well-lit water, providing ample resources for abundant plankton and algae growth. Their complex structure and high biological productivity make them the most diverse aquatic habitats, rivaling terrestrial tropical rain forests in number of species per unit area. Coral reefs are sensitive to environmental conditions and prone to "bleaching," which occurs when host coral animals expel their algae companions. Bleaching can occur for various reasons, but recent episodes seem to be associated with high ocean temperatures. Although coral can recover from bleaching, increased global temperatures due to global warming (see Chapter 4) may lead to more frequent bleaching and the death of especially sensitive reef systems.

Estuaries. The zone where freshwater rivers drain into salty oceans is known as an **estuary** (Figure 15.27). The mixing of fresh and salt water that occurs in

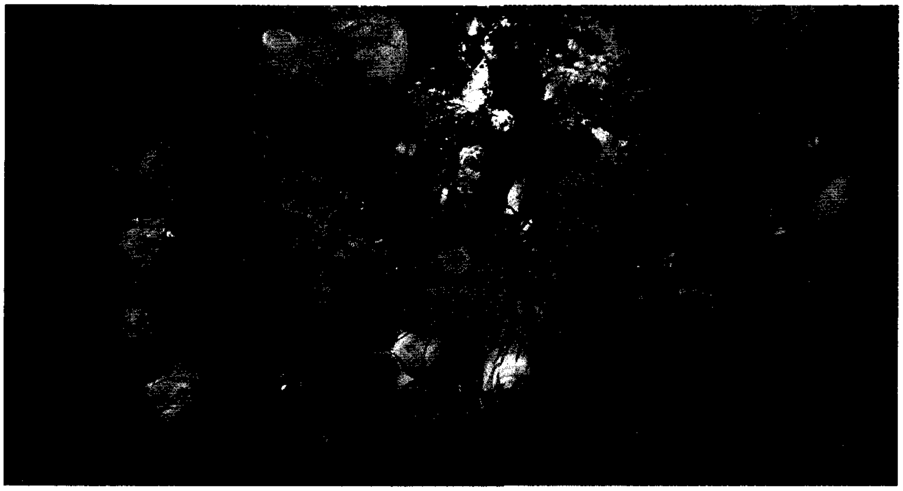


Figure 15.26 Coral reefs. These coral animals have their filtering appendages extended and are straining small pieces of organic matter from the water. Most of their calories are provided from the algae that live in their bodies and give the animals in this picture their orange color.

estuaries, combined with water-level fluctuations produced by tides, creates a unique habitat that is extremely productive, just as in freshwater wetlands. Estuaries provide a habitat for up to 75% of commercial fish populations and 80% to 90% of recreational fish populations; they are sometimes called the "nurseries of the sea." Estuaries are also rich sources of shellfish—crabs, lobsters, and clams. Vegetation surrounding estuaries, including extensive salt marshes consisting of wetland plants that can withstand the elevated saltiness compared to freshwater, provides a buffer zone that stabilizes a shoreline and prevents erosion. Some familiar and economically important estuaries are Tampa Bay, Puget Sound, and Chesapeake Bay.

Estuaries benefit people economically by providing shellfish and ocean fish production, protection from erosion, and recreational resources. Unfortunately, estuaries are threatened by human activity as well, including eutrophication from increasing fertilizer pollution and outright loss as a result of housing and resort development.

As is clear from our discussion of both aquatic and terrestial biomes, no habitat on Earth has escaped the effects of humans. Consequently, in order to truly understand our biological addresses, we must learn how human populations

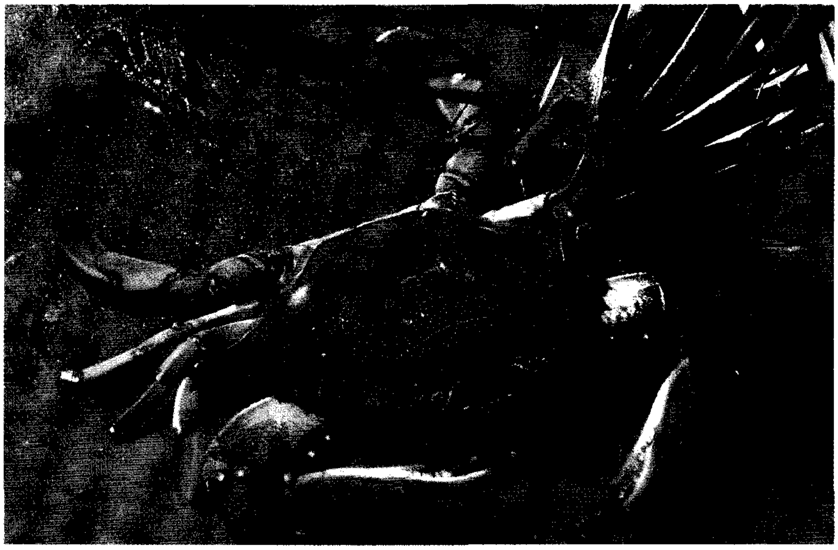


Figure 15.27 Estuary. The estuary in Chesapeake Bay is the largest in North America; it supports an enormous number of organisms, some with significant commercial value, such as the blue crab.

use the environment. Preserving our biological neighborhoods requires being able to meet human needs and at the same time respecting the needs of other species with which we coexist.

Know Your Bioregion: What are the aquatic habitats nearest to you? Can you name some of the dominant species in these habitats? What threats do these habitats face in your area?

15.4 Human Habitats

According to the United Nations Food and Agriculture Organization, humans have modified 50% of Earth's land surface for our own use. Most of this modification has resulted from agriculture and forestry, but a surprisingly large amount—2% to 3% of Earth's land surface, or 3 to 4.5 million square kilometers (larger than the area of India)—has been modified for human habitation (Figure 15.28). And this is only direct conversion; a human settlement has environmental effects far beyond its geographic boundaries, including the conversion of natural landscapes to agriculture and the changes to Earth's atmosphere, which receives some of our waste. In fact, because our activities have changed the very atmosphere of Earth, it is fair to say that no natural habitat has escaped human-caused alteration.

At the beginning of the nineteenth century, 98% of the human population lived in rural areas, where they were dependent on agriculture or harvesting natural resources for survival. As the Industrial Revolution accelerated and expanded, that pattern began to change. By 1950, one-third of the 2.5-billion human population lived in cities. Today, half of the human population of over 6 billion lives in cities. If current trends continue—which appears likely—by the year 2050, two-thirds of the population, nearly 6 billion people, will live in urban areas. Clearly, cities are going to become increasingly important in determining the human impact on native biomes.

Energy and Natural Resources

Consider the requirements of a forest. The only energy required for its growth is the solar irradiance striking the area, and the only nutrients available to support this growth are what is already present in the soil and slowly being increased by the activities of bacteria. In addition, nearly all of the "waste" produced by the organisms in a forest biome is processed on site; that is, it becomes part of the soil or air and is recycled endlessly. Thus forests are limited by the solar energy they receive and are enmeshed in material cycles that tend to preserve the nutrients needed for growth in a given area. In contrast, cities rely extensively on energy

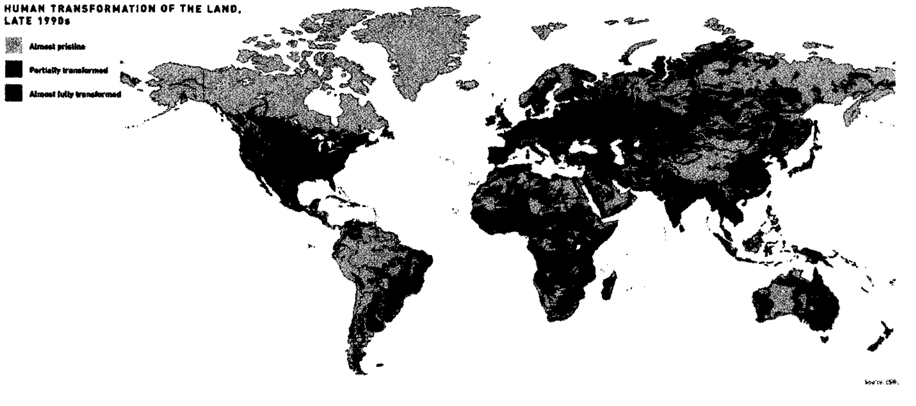


Figure 15.28 Human modification of Earth's land surface. About half of Earth's land surface remains relatively untouched by humans; most of the pristine land lies in the vast boreal forest covering much of Canada and Siberia, the great deserts of Africa and Australia, and the dense Amazonian rain forest in north and central South America.

imported from elsewhere and tend to be the central link in a linear flow of materials—from natural or agricultural landscapes, through the cities, and into waste disposed of elsewhere. Cities are very different from most typical biomes.

Energy Use. In more developed countries, much of the energy required to power the activities within cities—from running buses and heating and cooling buildings to lighting traffic signals and energizing wireless phones—is derived from fossil fuels. These fuels, extracted from wells and mines around the globe, include the region surrounding the Persian Gulf, source of much of the world's oil, and the Appalachian Mountains, a rich source of coal. For most people in developed countries, the energy we use is not associated with the bioregion in which we live. The environmental impacts of acquiring and transporting fossil fuel can be substantial, ranging from the degradation of oceans and estuaries resulting from oil spills to the wholesale dismantling of forested mountains during coal mining (Figure 15.29).

In less developed countries, fossil fuel use is still relatively small, and energy sources are more directly tied to the surrounding natural environment. A primary source of energy for heating and cooking in these countries is wood and other plant-based materials (including the dung of plant-eating animals). As urban areas in less developed countries grow, surrounding forests are stripped of trees, sometimes at a faster rate than they can be replaced. In both less developed and more developed countries, an awareness of cleaner sources of energy within a given bioregion—such as abundant solar or wind resources—could help to reduce the environmental costs of energy consumption in the region's urban areas.

Know Your Bioregion: What is the primary source for the electricity you use in your home? Is your bioregion rich in any less environmentally damaging energy resources?

Natural Resources. In addition to energy, human settlements require materials for survival—food from agricultural production and harvesting of natural resources, metals and salts from mines, fresh water for human and industrial consumption, petroleum for asphalt and manufactured goods, and trees for processing into paper and packaging. Developing and extracting all these raw materials changes biomes far from a city's center. The amount of material needed to support a city can be tremendous. A year 2000 estimate calculated that the **ecological footprint** of the city of London—that is, the amount of land needed to support the human activity there—was 293 times the actual size of the city, equal to twice the entire land surface of the United Kingdom. Clearly, the resources to support London must come from other countries around the world—from the boreal forests of Russia and Scandinavia that supply wood for building and paper production to the tropical forests of India and China that supply Londoners' daily spot of tea. There is no reason to believe that London is exceptional; most cities in more developed countries likely have similarly-sized footprints. Cities' footprints can be reduced by their citizens, especially if they reduce the amount of energy used for transportation and make sensitive consumer choices, including buying locally produced foods and less meat.

Know Your Bioregion: What agricultural products are produced in your bioregion? How easy is it to buy local produce? What other natural resources does your bioregion supply?

Waste Production

The ecological footprint calculated for London includes not only the land needed to provide resources but also that required to handle the city's waste. The waste produced by a city presents a special problem. The density of the human population is so great in cities that specialized systems are required to handle the enormous amounts of human waste generated in a small area.

Figure 15.29 The cost of fossil fuel extraction. Much of the remaining coal in West Virginia is found hundreds of feet below the surface of steep mountains. In the 1970s, mining companies developed a technique known as "mountaintop removal"—using explosives to blast off the rock above the coal deposit and dumping the waste rock into nearby valleys—to access this coal. Since 1981, more than 500 square miles of West Virginia have been destroyed by this method of mining.

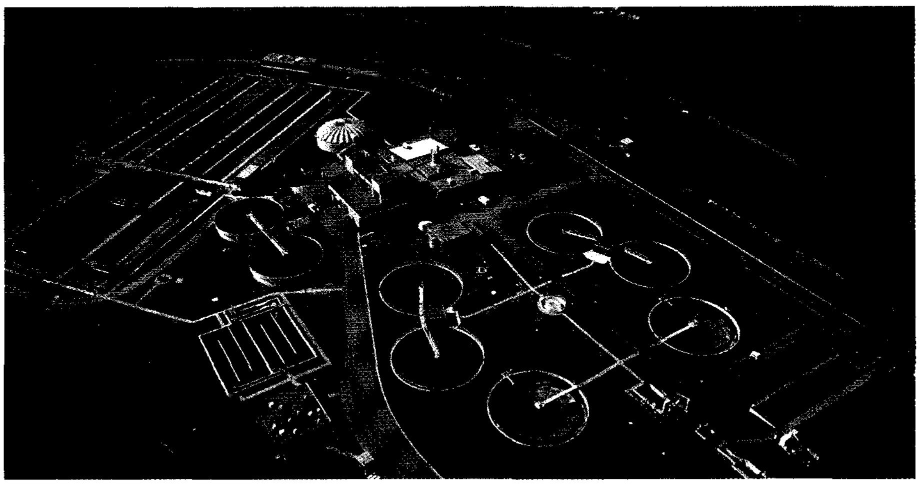


Figure 15.30 Treatment of human waste. *In more developed countries, human waste is treated in expensive and technologically advanced sewage treatment plants.* Water entering the plant is first treated with oxygen to increase decomposition activity, sent to settling ponds to remove solids, and treated with chlorine or another disinfectant before being released into a nearby waterway. Solids are compacted and either sent to a nearby landfill or composted at high temperatures to produce a soil fertilizer.

Human wastes can be liquid, in the form of wastewater; solid, in the form of garbage; or gaseous, in the form of air pollution.

Wastewater. In developed countries, cities have sewage treatment systems to handle the **wastewater** that drains from sinks, tubs, toilets, and industrial plants (Figure 15.30). These systems typically treat water by removing semisolid wastes through settling, using chemical treatment to kill any disease-causing microorganisms, and eventually discharging the treated water to lakes, streams, or oceans. Unfortunately, older treatment systems can be overwhelmed by storm water, causing the discharge of large volumes of wastewater directly into waterways. Untreated wastewater can cause nutrient levels to spike and algae and bacteria growth to increase, thus leading to beaches being closed to swimming and other water-based recreation. Huntington Beach, one of the most famous surf spots in California, was closed for nearly the entire summer of 1999 because of untreated wastewater flowing into the ocean there.

Semisolid wastes, called sludge, are often composted (that is, allowed to decompose via the action of bacteria and fungi) and applied to land as fertilizer or trucked to landfills for burial. Land application of sewage sludge has its own problems; this material contains not only human waste—a valuable fertilizer if properly composted—but also industrial wastewater, which can contain a wide variety of toxic chemicals. A major challenge of the wastewater treatment industry in developed countries is the safe and effective disposal of sewage sludge.

In less developed countries, safe disposal of treated sewage from rapidly growing cities may be a distant dream. In many rapidly industrialized regions, the emigration of people to urban areas has overwhelmed antiquated and inadequate sewer systems. Large numbers of people in these cities live in slums where running water is scarce, and untreated human waste flows in open gutters. The consequences of inadequate disposal of human waste can be severe—intestinal diseases due to contact with waste-contaminated drinking water cause the preventable deaths of over 2 million children under 5 years old every year.

Know Your Bioregion: Where does your wastewater go? Does your community have any problems handling wastewater and sewage?

Figure 15.31 Disposal of garbage. *Solid waste contained in a sanitary landfill is locked within a thick liner and surrounded by a drainage system that collects all water releasing from or leaching through the waste.* Garbage is compacted and "capped" with soil or other material as soon as it is dumped. Much of the waste sent to sanitary landfills in the United States could be recycled or composted.

Garbage and Recycling. In addition to dealing with wastewater, people in urban areas also must find ways to control their **solid waste**—that is, their garbage. In more developed countries, most of the solid waste finds its way into sanitary landfills, which are pits lined with resistant material such as plastic. Landfills have systems for collecting liquid that drains through the waste, and exhaust pipes to vent dangerous gases that may build up as a result of decomposing waste (Figure 15.31). As nearby communities fight the development of new landfills, and older ones reach their maximum capacity, landfill space is becoming more and more limited and farther removed from cities. To stave off a looming "garbage crisis," many states and communities mandate high levels of recycling of paper, glass, and metal; and many have or are considering community-wide composting programs to reduce the amount of food and yard waste trucked to landfills. Unfortunately, even in cities and states where recycling rates are relatively high, household garbage production continues to increase. In less developed countries, the problem of solid waste disposal is more severe. Many large cities in these areas have large, open dumps in which unstable, fire-prone piles of garbage provide living space for desperately poor immigrants in the city.

Know Your Bioregion: Where does your garbage go? What is the rate of recycling in your community, and can it be improved?

Air Pollution. Because of human dependence on fossil fuels, urban areas produce large amounts of gaseous waste. These air emissions include carbon dioxide, a chief contributor to global warming (see Chapter 4), as well as combustion by-products including nitrogen and sulfur oxides, small airborne particulates, and fuel contaminants such as mercury. Exposure to sunlight and high temperatures can cause some of these by-products to react with oxygen in the air to form ground-level ozone or **smog** (Figure 15.32). For individuals with asthma, heart disease, or reduced lung function, increased ozone levels can lead to severe illness, even death. When the gaseous pollution produced by human settlements enters the upper reaches of Earth's atmosphere, it can be carried on air currents throughout the globe. Air emissions from coal-fired power plants throughout the Midwest cause severe acid rain, even in lightly settled regions of the northeast United States, and airborne toxins such as benzene and PCB have been found in high levels in animals in the seemingly pristine Arctic.

Air pollution is a problem in both developed and less developed countries. In less developed countries, pollution control is weak or lacking altogether; in more developed countries, the sheer volume of fossil fuel use contributes to poor air quality. In the United States, the number of miles driven by car per household has nearly doubled in the last 25 years, partially due to an increase in the distance that individuals live from their workplaces. Development of suburban settlements outside the geographical limits of cities has been termed **urban sprawl**. Urban sprawl not only contributes to an increase in fossil fuel consumption by causing increased transportation needs but also affects wildlife through habitat destruction and fragmentation (see Chapter 14). Urban sprawl also impairs water quality via the destruction of wetlands and the increasing amount of paved and built surfaces, which then funnel pollutants and warmed water into urban lakes, streams, and rivers.

Figure 15.32 The effect of waste gas emissions. The brownish haze over downtown Los Angeles, California in this picture is smog, resulting from automobile emissions and other air pollutants causing the conversion of oxygen to ozone in sunny, still conditions. Days like this one can be sickening or deadly for people with impaired lung function.

Know Your Bioregion: How is the air quality in your community? What are the major air pollutants and their sources?

The effect of human settlements on surrounding natural biomes can be significant and severe, as we have discovered in this chapter. However, many of these impacts can be mitigated with thoughtful planning and the use of improved technology. In the United States, laws such as the Clean Air Act and the Clean Water Act—passed in 1970 and 1972, respectively—have greatly reduced air and water pollution and have contributed to the recovery of once severely impaired habitats (Figure 15.33). Cities throughout the more developed world are supporting projects aimed at creating sustainable communities that are both economically vital and environmentally "intelligent." Perhaps by getting to know our biological neighbors and understanding how our choices affect these organisms, we can be inspired to help create communities that are safe and healthy for humans and other species.

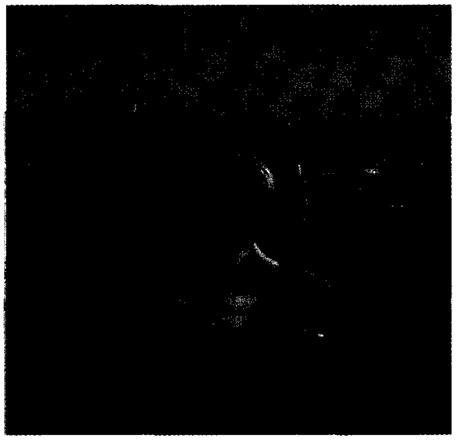


Figure 15.33 Fitting human needs into the bioregion. These bathers are enjoying Lake Erie; once so polluted that it was considered "dead" in the 1960s, the lake has now recovered and provides clean swimming beaches and a healthy fish population. The lake's recovery provides hope that other threatened biomes and habitats can support sustainable human settlements with our thoughtful efforts.

CHAPTER REVIEW

Summary

15.1 Global and Regional Climate

- Climate is the weather of a place as measured over many years. Climate in an area is determined by global temperature patterns, which are driven by solar irradiance and local factors such as proximity to large bodies of water (pp. 392–393).
- Temperatures are warmer at the equator than at the poles because solar irradiance is greater at the equator (pp. 393–394).
- Seasonal changes are caused by the tilt of Earth's axis. For example, during summer in the Northern Hemisphere, total solar irradiance during the day is much greater than it is during winter (pp. 394–395).
- Local temperatures are influenced by altitude, proximity to a large body of water, nearby ocean currents, the light reflectance of the land surface, and the amount of surrounding vegetation (p. 396).
- Global precipitation patterns are driven by solar energy, with areas of heavy rainfall near the solar equator and dry regions at latitudes of 30° north and south of the equator (p. 399).
- Local precipitation patterns are influenced by the presence of a large body of water, which tends to increase rainfall, and the presence of a mountain range, which tends to reduce rainfall on its leeward or sheltered side (p. 400).

Web Tutorial 15.1 Tropical Atmospheric Circulation and Global Climate

15.2 Terrestrial Biomes

- Categories of primary vegetation types found on Earth's land surface are called biomes (p. 400).
- Forests are dominated by trees and categorized by distance from the equator into tropical, temperate, and boreal types (p. 401).
- The chaparral biome is dominated by woody shrubs (p. 404).
- The major vegetation type on grasslands is nonwoody grasses. These biomes are categorized by distance from the equator into tropical and temperate types (p. 405).
- Deserts are found where precipitation is 50 cm (20 in) per year or less and contain mostly drought-resistant plants (pp. 406–407).
- Tundra occurs in areas where the growing season is less than 60 days, both near the poles and at high altitudes (p. 408).

15.3 Aquatic Biomes

- Freshwater biomes include lakes, rivers, and wetlands (p. 409).
- Marine biomes include oceans, coral reefs, and estuaries (p. 411)

15.4 Human Habitats

- Humans have modified over 50% of Earth's land surface; much of this modification now supports the activities of cities (p. 414).
- Cities must rely on imported energy and other resources to survive; extraction of these resources carries an environmental cost felt by other bioregions (p. 415).
- Waste disposal is a significant challenge for large urban areas. Sewage must be treated to avoid contaminating drinking water; garbage must be disposed of effectively, and air emissions must be controlled. More developed countries have more resources to consume and handle

the vast amounts of waste that they produce, while less developed countries struggle with inadequate systems (pp. 415–416).

- Increasing the bioregional awareness of citizens and communities can help them devise methods for supporting human activities in a more sustainable manner (pp. 417–418).

Learning the Basics

1. Explain why the northern United States experiences a cold season in winter and a warm season in summer.
2. Why does proximity to a large body of water moderate climate on a nearby landmass?
3. Compare and contrast tropical, temperate, and boreal forests.
4. The solar equator, the region of Earth where the sun is directly overhead, moves from 23° N to 23° S latitudes and back over the course of a year. Why?

   A. Earth wobbles on its axis during the year.; **B.** The position of the poles changes by this amount annually.; **C.** Earth's axis is 23° from perpendicular to the sun's rays.; **D.** Earth moves 23° toward the sun in summer and 23° away from the sun in winter.; **E.** Ocean currents carry heat from the tropical ocean north in summer and south in winter.
5. A land area's climate is determined by ______________.

   A. annual average solar irradiance; **B.** whether or not it is near a large body of water; **C.** the amount of variation in solar irradiance over the course of a year; **D.** the area's altitude; **E.** all of the above
6. The biome type characterized by evergreen coniferous trees and low average temperature is ______________.

   A. chaparral; **B.** desert; **C.** temperate forest; **D.** tundra; **E.** boreal forest
7. Tundra is found ______________.

   A. where average temperatures are low, and growing seasons are short; **B.** near the poles; **C.** at high altitudes; **D.** a and b are correct; **E.** a, b, and c are correct
8. Which statement best describes the desert biome?

   A. It is found wherever temperatures are high.; **B.** It contains the largest amount of biomass per unit area than any other biome.; **C.** Its dominant vegetation is adapted to conserve water.; **D.** Most are located at the equator.; **E.** It is not suitable for human habitation.
9. Which of the following biomes has a structure made up primarily of the remains of its dominant organisms?

   A. coral reefs; **B.** freshwater lakes; **C.** rivers; **D.** estuaries; **E.** oceans
10. In more developed countries, wastewater containing human waste ______________.

    A. is dumped directly into waterways; **B.** is applied directly to farm fields; **C.** is piped into sanitary landfills; **D.** is treated to remove sludge and disease-causing organisms and released into nearby waterways; **E.** is a major source of infectious disease in human populations

Analyzing and Applying the Basics

1. Consider the following geographic factors, and predict both the climate and biome type found in the location described. Explain the reasoning that you used to determine your answer. This small city is:
   - On the coast of the Pacific Ocean
   - 20° north of the equator
   - Altitude of 200 meters above sea level
   - At the base of a mountain range
2. One prediction of global climate change models is that significant amounts of melting ice will change the salt content of the ocean, causing the Gulf Stream in the Atlantic Ocean to stop altogether. How will this change likely affect Europe?

Connecting the Science

1. How many biomes do you rely on to supply your food? Many grocery stores label the origin of their produce. The next time you go to the grocery store, try to determine the number of different countries from which your produce comes. Could you easily change your diet and shopping habits to rely on locally produced food? Why or why not?
2. Consider the setting of your home. What kind of changes to the environment of your home would help it fit better into the bioregion? Are these changes feasible? Are they desirable?