The Earth formed approximately 4.5 billion years ago. At first, the planet was a barren mass of rock and ice. Over billions of years, however, life evolved. Today, the Earth's surface is carpeted with a rich and diverse array of life forms existing in a complex web of life. As anyone who has traveled across any major continent knows, however, the biosphere varies from one region to the next. That is to say, the biosphere is divided into distinct regions, which ecologists call **biomes**. Biomes differ from one another in climate—that is, in rainfall, sunlight, temperature, and other abiotic factors. These differences, in turn, lead to marked variations in the types and abundance of species.
CRITICAL THINKING

Exercise

An article in Science News reports on studies by a scientist who examined sonar measurements of ice thickness in the Arctic Sea near the North Pole. He studied assessments made by two British submarines that took similar routes across the Arctic in 1976 and 1987. During the first trip, the average ice thickness was 5.3 meters (17.5 feet), and on the second trip, it was 4.5 meters (14.85 feet).

To some scientists, these data suggest that the Arctic ice is melting, a sign that global warming may be occurring. What questions would you ask to determine the validity of this conclusion? Write them down. What additional information might be helpful in analyzing the possibility that the polar ice caps are shrinking?

The Earth’s surface is also covered by massive bodies of water. These, too, have distinct regions, known as aquatic life zones. The characteristics of these regions are also determined by abiotic factors.

This chapter describes the major biomes and aquatic life zones and outlines some threats to them. It also offers suggestions for protecting the world’s rich biological legacy and points out how important protection is for the survival of people and the many other species that share this planet with us. Before we discuss these topics, however, let’s review some facts about weather and climate, which determine the biotic community of a region.

5.1 Weather and Climate: An Introduction

Most of us have heard the terms weather and climate many times in our lives, but have you ever stopped to consider what they mean and what factors determine what the weather and climate are like?

Weather refers to the daily conditions in our surroundings, including temperature and rainfall. Weather changes constantly from week to week, day to day, and even hour to hour. Climate is the average weather over a long period—approximately 30 years. As one wind energy expert told me, climate is what you expect, weather is what you get.

The climate of a region determines what plants can live in an area. Dry climates such as those found in the desert are home to cacti and other plants that are adapted to survive with little rainfall. Wetter climates such as those of the tropical rain forest are home to a wide variety of plants for which water conservation is not a major concern. Plant life forms the base of grazer food chains and is the source of nutrients and energy for all other species. It also helps to determine the characteristic animal life.

Major Factors that Determine Weather and Climate

Several factors determine a region’s weather patterns and, ultimately, its climate. First is the amount of light and heat that strike different parts of the Earth. These come from the sun. As shown in FIGURE 5-1, the Earth can be divided into three climatic zones: tropics, the temperate zones, and the polar regions. The tropics lie on either side of the equator between 30° north and 30° south latitudes. They receive the most light and heat energy from the sun and are the warmest. The temperate zones lie between 30° and 60°, both north and south latitudes. They receive less heat and sunlight and are therefore cooler. The poles receive the least amount of solar energy and are the coolest.

The unequal heating of the Earth—and the three major climatic zones that occur as a result—are the product of the Earth’s tilt (Figure 5-1). Tropical regions receive the most direct sunlight and are, therefore, the hottest. Temperate and polar regions receive sunlight that filters through more atmosphere, which reduces heating. Besides influencing climate, the unequal heating of the Earth’s surface creates air and water currents that profoundly influence the climate of the Earth. Let’s begin with the wind currents.

When air is heated, it expands and becomes less dense. As shown in FIGURE 5-2a, hot air in the tropics rises and
moves toward the poles, transporting heat and moisture from the equator to the poles. Cold air from the poles tends to move southward in the northern hemisphere toward the equator. These phenomena create a general air circulation pattern between the equator and the poles that tends to distribute excess heat from the equator throughout the globe.

KEY CONCEPTS
The Earth is unequally heated, which creates three major climatic zones: tropical, temperate, and polar. Air tends to flow from the equator to the poles.

The Coriolis Effect and Topography
Air circulation is actually a bit more complicated than the previous discussion might lead you to believe. In the northern hemisphere, for example, warm air from the equator rises and moves northward. As it moves northward, much of its moisture is lost as rainfall over the tropics. As the air moves northward it also cools, and some of it sinks back to the Earth’s surface (Figure 5-2b). This air flows back toward the equator, creating winds that blow toward the equator called the trade winds (Figure 5-2c).

The rest of the equatorial air continues northward over the temperate zone. This air is relatively dry, having lost much of its moisture in the tropics. As Figure 5-2b shows, the air circulating toward the north pole splits into higher and lower level winds—both flowing generally northward. However, as the lower-level air travels northward it picks up moisture from the temperate zone, which it deposits as rainfall and snow. When the equatorial air reaches the poles, it is cold and very dry. It then begins its way back to the equator (Figure 5-2b).

This general circulation distributes heat and moisture throughout the planet. It makes the poles warmer than they might otherwise be and makes the tropics a bit cooler. The distribution of heat and moisture caused by air flow also helps determine weather. However, this distribution is complicated a bit by the fact that Earth spins on its axis. This, in turn, shifts the wind direction and helps to create distinct climatic zones within the major regions.

Figure 5-2c shows three distinct wind patterns, one in each zone of the northern hemisphere. The trade winds blow toward the equator, but they don’t blow directly south. In the Northern hemisphere, they blow from northeast to southwest. The low-level winds in the temperate zone, called the westerries, generally blow from south to north (as shown in Figure 5-2b) and are deflected a bit, blowing southwest to northeast. The polar easterlies, cold Arctic air that sinks back toward the equator, blow from northeast to southwest.

Scientists call the deflection of wind currents by the spin of the Earth the Coriolis (CORE-ee-ole-iss) effect. To understand this phenomenon, suppose that a punter kicks a football 50 yards south; the ball is in the air for 5 seconds, and it flies in a perfectly straight course. If this were so, you would expect it to land in a perfectly straight line from the kicker. It does not. In actuality, it lands a little less than half an inch off target, just west of the straight line. The reason for this is the Earth’s spin. While the ball is in the air in a straight path, the Earth is spinning underneath it. The path of the ball thus appears to be deflected. Air flowing along the Earth’s surface is also deflected because of the Earth’s spin. Thus, the trade winds, the westerlies, and the easterlies are produced by the Earth’s rotation. Wind currents, instead of flowing straight north or south (as they would if the Earth did not spin), actually flow across continents. Why is this worth noting?

As noted previously, wind currents help to determine weather patterns. In the United States, moist air tends to flow from the Pacific Ocean (southwesterly) across the continent (toward the northeast). Topography then comes into play. Mountain ranges along the West Coast and in the interior, for example, rob some of the moisture carried in this air, creating deserts or semiarid lands on their downwind side. This occurs because mountains thrust warm, moist air upward. As it rises it cools, and the moisture condenses and falls as precipitation. When the air comes down the other side of the mountain range, it is drier. Little precipitation falls, and the area is either desert or semidesert (Figure 5-3). This phenomenon is called the rain shadow effect. As the air flows across the Great Plains, it picks up and depots moisture downwind. Rainfall increases as one travels eastward. This
increase in precipitation, in turn, explains why the prairie due east of the Rocky Mountains starts off as short grass, which requires little rain, but gradually becomes tallgrass prairie and then deciduous forest from eastern Kansas eastward.

**KEY CONCEPTS**

Weather within the major climatic zones is altered by wind flow patterns, which are profoundly influenced by the spin of the Earth. Weather is also affected by topography, especially mountain ranges.

### Ocean Currents

Climate is also influenced by ocean currents. At the equator, water warmed by the sun rises and tends to drift toward both poles, creating huge currents. The Gulf Stream, shown in **FIGURE 5-4**, is a good example. The warm water of the Gulf Stream flows northward, affecting the climate of landmasses that it passes near. The Gulf Stream, for instance, warms England and the rest of Europe and produces much milder winters than would be expected otherwise. Northern Japan and Alaska are also much warmer than one would predict based on their location because of a warm-water current traveling up from the equator (North Equatorial current). Should these currents cease, they could bring about massive climate changes (cooling) in these areas. Global warming could alter ocean currents, bringing about massive cooling. How warming can effect these changes is discussed in Chapter 20.

As the warm-water currents move northward, however, they begin to cool. As the waters cool, they sink and then flow back toward the equator, in much the same way that cold Arctic air tends to flow toward the equator. Cold water returning to the equator creates broad, deep currents in the opposite direction of the warm-water surface currents. As shown in **FIGURE 5-4**, the cold water Humboldt current flows up from the south pole, bringing cold, deep waters toward the equator. This water eventually emerges at the surface in regions called *upwellings*. Because it is rich in nutrients, it supports a diverse aquatic community of great ecological and economic value. Every 10 years or so, the Humboldt current turns warm, a phenomenon called *El Niño*. This creates heavy rain and rough seas, which

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**FIGURE 5-3**  
*Rain shadow effect.* This shows the effect of mountain ranges on rainfall.

**FIGURE 5-4**  
*Major ocean currents.*
can have a devastating effect on coastal communities and often affects weather worldwide. (Today, El Niños are occurring more frequently, quite possibly as a result of global climate change.)

Weather is much more complicated than discussed here, but this introduction gives you an overview that may help you understand why particular biomes are located where they are. It will also help you to understand some major global environmental issues, such as global climate change.

**KEY CONCEPTS**

Warm water from the equator flows toward the poles, warming landmasses near which it passes. As it flows northward, it cools. Cool water eventually sinks, and flows back toward the equator, creating a huge global circulation pattern.

### 5.2 The Biomes

We begin our journey through the Earth’s diverse biomes ([FIGURE 5-5](#)) in the north and work our way south. On this journey, you will learn about the climate of several key biomes and the unique biological characteristics (or adaptations) that permit plants and animals to thrive within them. As you will see, each biome is characterized by a dominant form of vegetation. However, within any given biome, regional differences in climate (and other factors such as soil) can alter the composition and abundance of species. The study of biomes underscores an important lesson, presented in Chapter 6: Life can adapt to a wide range of conditions. In the frozen tundra, for example, some organisms survive in air temperatures as low as −70°C (−90°F). In contrast, some desert species can tolerate 50°C (120°F).

**KEY CONCEPTS**

The Earth’s surface can be divided into biologically distinct zones called biomes, each with a distinct climate and unique assemblage of plants and animals. Nevertheless, regional variations occur within each biome.

### The Tundra

Stretching across the northernmost portions of North America, Europe, and Asia is the Arctic tundra. The Arctic tundra...
is the northern limit to plant growth. Covering about 10% of the land mass of the Earth, the tundra lies between a region of perpetual ice and snow to the north and a band of coniferous forests to the south. The tundra is a treeless tract characterized by grasses, shrubs, and matlike vegetation (mosses and lichens) adapted to the harsh climate.

The Arctic tundra receives very little precipitation (less than 25 centimeters, or 10 inches, a year), and most precipitation occurs in the summer. During the long, cold winters, the mean average temperature remains well below zero for months on end. Because Arctic summers are short and winters are so cold, the deeper layers of soil remain frozen throughout the year and are called permafrost.

The permafrost and the harsh winters of the Arctic tundra prevent deep-rooted plants such as trees from growing there. In the brief Arctic summer, however, the long days and relatively warm temperatures permit the superficial layers of soil to melt. Because evaporation is low and because water from melted snow and ice cannot percolate downward into the soil in the summer (due to the permafrost), the tundra becomes dotted with shallow ponds, lakes, and bogs (FIGURE 5-6).

During the summer months, the tundra comes alive with insects (mosquitoes and black flies) and birds that migrate north to nest on the rolling plains. The birds feed on the swarms of insects, raise their young, and then migrate south with their offspring, often in great flocks.

Despite the harsh conditions, a variety of animals live year round on the tundra. Ptarmigan, musk oxen, and arctic hares, for example, are adapted to the extreme cold (FIGURE 5-7). Animals survive by living in burrows or by having thick layers of insulation or a large body size (which retains heat well). Some animals, like caribou, are migratory, moving southward when winter comes.

The tundra is a fragile environment, easily damaged by human actions. The short growing season provides little time for vegetation to recover from damage caused by mining, oil and gas development, and other human activities. Tire tracks that destroy vegetation on the tundra take many decades to heal. Damage caused by spills of oil or hazardous waste may take much longer.

Nowhere is the threat to the tundra greater than in northern Alaska. Alaska’s northern coastline is approximately 1,760 kilometers (1,100 miles) long, and all of it except a 184-kilometer (115-mile) stretch, which is part of the Arctic National Wildlife Refuge (ANWR), one of the last great wilderness areas on the planet, is open to oil and gas exploration and development. Efforts are under way to

**FIGURE 5-6** The tundra. In the summer, water collects on the surface because evaporation is low and because water percolation into the ground is prevented by the permafrost.

**FIGURE 5-7** Tundra species. (a) The ptarmigan and (b) musk ox are both well adapted for life in the cold Arctic tundra.
open that section to development as well, despite almost overwhelming public opposition.

Many conservationists and citizens fear that the region will be turned into a network of roads, airports, power plants, oil platforms, waste ponds, buildings, and gravel pits—to supply oil to make fuel for cars and other motorized vehicles (FIGURE 5-8). Proponents of oil development in the ANWR believe that wildlife and oil development can peacefully co-exist despite estimates by biologists suggesting that full-scale oil development will result in a 20 to 40% decline in the large caribou herds that spend their summers in the region. Biologists also predict that full-scale oil development will wipe out half of the existing musk ox population. Populations of grizzly bears, polar bears, wolverines, and other animals are likely to decline, too. Oil development in the region would also result in air pollution, water pollution, and noise. Oil spills and hazardous waste disposal on the tundra are common in nearby Prudhoe Bay. In fact, the U.S. Department of Interior has recorded over 17,000 oil spills in the Arctic since 1973. Proponents are currently planning on developing only a small portion of ANWR, but critics are worried that after development commences, proponents will call for further development that could be devastating to this pristine area. For more on this controversial issue, see Chapter 14.

KEY CONCEPTS

The Arctic tundra, the northernmost biome, is characterized by the harshest climate. Because the growing season is so short, life on the Arctic tundra is extremely vulnerable to human actions.

The Taiga

Just south of the tundra is a wide band of cone-bearing, or coniferous, trees (pine, fir, and spruce). It extends across Canada, part of Europe, and Asia and constitutes the taiga (TIE-ga), or northern coniferous forest biome (Figure 5-5). The taiga, which a student of mine once defined as a “carnivorous forest” on his test, has a longer growing season than its northern neighbor, the tundra. It also receives far more precipitation.

In the summer, the subsoil of the taiga thaws, permitting deep-rooted plants such as trees to live. But the summer growing season is still short in comparison with that in the southern biomes (grassland and temperate deciduous forest). The rather cold, snowy winters and limited growing season of the taiga have resulted in numerous adaptations. Few organisms illustrate these adaptations as well as conifers, trees that remain green throughout the year. Conifers have narrow, pointed leaves called needles. Needles contain photosynthetic cells and are retained throughout the year, allowing conifers to continue to photosynthesize (albeit slowly) throughout the winter. The presence of needles throughout the year also permits the plant to make the most of the growing season. Unlike the deciduous hardwoods of the south, which lose their leaves in the winter and must develop new ones each growing season, conifers can take immediate advantage of the sunlight, moisture, and warmer weather of spring.

Retaining needles may help conifers survive in the taiga’s short growing season, but it also creates a problem: The needles tend to capture snow. Instead of breaking under the weight of snow, though, the branches of conifers are adapted to bend and shed snow. Another adaptation of great importance to conifers is the waxy coating found on their needles. This layer greatly reduces evaporation. Because water transport up the tree from the ground is restricted during the winter, the waxy coating prevents the needles from drying out and helps the tree survive.

As anyone who has flown east to west over Canada will attest, the dense coniferous forests of the taiga extend for miles on end. These forests are interspersed with meadows, lakes, ponds, and rivers. Together, they support a variety of species such as bears, moose, and deer. Many smaller mammals also make their home there, including foxes, wolverines, and snowshoe hares. Because of the relatively cold winter and short growing season, however, species diversity in the taiga is fairly low compared with that in biomes to the south.

Along the west coast of North America, the forests of the taiga are bathed in moisture from the Pacific Ocean. Because the ocean moderates temperature, this region enjoys a long growing season. Consequently, forests in this area contain some of the world’s largest trees. Heavy pressure from timber companies and consumers, however, is now destroying many of these magnificent trees and the species that live in them (FIGURE 5-9).
Efforts are under way to reduce the overcutting, but in many areas of Canada and the United States, powerful logging companies are resisting. The U.S. Congress, however, reduced cutting in the Tongass National Forest of Alaska and set aside a large tract of the forest for permanent protection.

**KEY CONCEPTS**

- **The Temperate Deciduous Forest Biome**

  The temperate deciduous forest biome is located in the eastern United States, Europe, and northeast China. In the United States, this biome is home to about half of the human population. Characterized by abundant precipitation and a long growing season (5 to 6 months), this biome supports a wide variety of plants and animals.

  The dominant plants of the temperate deciduous forest biome are **deciduous trees**—the broad-leaved trees that shed their leaves each year in the fall. Maple, oak, black cherry, and beech trees are examples (**FIGURE 5-10**). The loss of leaves in the fall is believed to be an adaptation that greatly reduces evaporation at a time when the supply of liquid water is limited.

  In the spring, new leaves develop from buds. In the relatively brief period after the ground has thawed and before the leaves have fully developed, numerous species of wildflowers sprout on the sunny forest floor. The shade created by deciduous trees, however, greatly limits plant growth on the forest floor throughout most of the rest of the growing season.

  The temperate deciduous forest biome is characterized by a deep, rich soil. The richness of the soil results from mineral and organic nutrients. The nutrients are drawn up through the roots and incorporated in the leaves. During the fall, the leaves detach and fall to the ground. There, they decay and release their nutrients into the soil.

  The fertile soil and abundant plant life of the forest support a rich and varied population of insects, microorganisms, birds, reptiles, amphibians, and mammals (**FIGURE 5-11**). Common mammals include the raccoon, white-tailed deer, red fox, and black bear.

  Ernest Hemingway once wrote that “a continent ages quickly once we come.” In fact, few biomes have been so heavily altered by human activities as the temperate deciduous forest. Large-scale destruction of the forests began when colonists first settled the continent. Early settlers cleared the forests to grow crops on the rich soil. They also cut trees to make room for homes, towns, orchards, and roads. In the United States, only about 10% of the land east of the Mississippi is still forested, and only about 0.1% of the original...
The Grassland Biome

Grasslands exist in temperate and tropical regions in areas that receive intermediate levels of precipitation—that is, less precipitation than forested regions but more than deserts (Table 5-1). Grasslands are found in North America, South America, Africa, Europe, Asia, and Australia.

In North America, grasslands form a continuous, wedge-shaped zone extending from the Gulf of Mexico northward through Canada to the taiga (Figure 5-5). A small area of grassland is found in the Great Basin, between the Cascade Mountains on the west and the Rockies on the east.

All grasslands bear a remarkable similarity (Figure 5-12). Most are on flat or slightly rolling terrain. Carpeted in thick grasses, the soils are probably the richest in the world as a result of thousands of years of plant growth and decay.

Table 5-1
Precipitation in Major Biomes

<table>
<thead>
<tr>
<th>Biome</th>
<th>Annual Precipitation (Centimeters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tundra</td>
<td>Under 25 (10)</td>
</tr>
<tr>
<td>Taiga</td>
<td>38 to 100 (15 to 40)</td>
</tr>
<tr>
<td>Temperate deciduous</td>
<td>75 to 150 (30 to 60)</td>
</tr>
<tr>
<td>Grassland</td>
<td>25 to 75 (10 to 30)</td>
</tr>
<tr>
<td>Desert</td>
<td>Under 25 (10)</td>
</tr>
<tr>
<td>Tropical rain forest</td>
<td>150 to 400 (60 to 160)</td>
</tr>
</tbody>
</table>
In the United States, the grasslands begin just east of the Rocky Mountains. The grasslands of eastern Colorado, however, are not as rich as those further east because of lower rainfall, as explained earlier. The grasslands of the eastern plains of Colorado, Wyoming, and Montana are known as the **shortgrass prairie**. Further east, as rain and snowfall increase, the shortgrass prairie gives way to the **tallgrass prairie** of the Dakotas, Nebraska, and eastern Kansas. Today, most of the tallgrass prairie has been destroyed by farming so that only small patches remain.

Grasslands are usually devoid of trees because they lack sufficient annual precipitation and experience periodic drought. Thus, the only trees found in the Great Plains of the United States are those that have been planted around homes and farms or those that live along streams and rivers.

Grasses, however, require less water than trees, and many species of grass send their roots deep into the Earth, drawing on reliable moisture supplies far below the surface. Grasses are also well adapted to periodic fires ignited by lightning. Fires burn the plant above the ground but do not harm the roots, from which new life can spring.

Because the soils of the grassland biome are so rich, they have been heavily exploited by people, primarily for agriculture, a practice that profoundly alters the plant and animal life. The grassland biome of North America, for example, once supported an enormous population of bison—perhaps as many as 60 million animals. Roaming the prairies, bison herds were so large that it would take men traveling on horseback 3 to 4 days to pass through a single herd. These animals were killed for food and sport and squeezed out of their habitat by the spread of farms.

The grassland biome of North America also supported grizzly bears and elk. As humans settled the grasslands and began to farm and raise cattle, grizzlies were exterminated. Elk herds fled to the protection of the Rocky Mountains, where they remain today. Many species—including deer, pronghorn antelope, badgers, and coyotes—still live on the grasslands of North America, sharing habitat with cattle, horses, sheep, and people.

In the grasslands, as in the temperate deciduous biome, farming has probably had the most significant impact of all human actions. Today, many of the world’s tallgrass prairies have been plowed under to plant corn, wheat, soybeans, and other crops. The shortgrass prairie, being drier and less productive, has fared much better. Except where irrigation water has allowed farmers to cultivate the land, much of the shortgrass prairie still exists. This land, however, is often overgrazed by cattle. Continual overgrazing eliminates many hardy grasses, and in the semiarid grasslands of North America (in Colorado, for example), it creates dry soil conditions suitable for the growth of weedy species such as sagebrush. Because cattle will not eat it, sagebrush thrives in overgrazed fields, eventually taking over. Throughout the West, once productive pastures have become overgrown with sagebrush (**FIGURE 5-13**). As you travel in eastern Wyoming and Colorado, look for fields of sagebrush; chances are that they are the result of overgrazing. With a little care, such an ecological tragedy could have been avoided.

Poor agricultural practices on farms and ranches in grasslands throughout the world have resulted in widespread soil erosion and desertification in the grassland biome (Chapter 12). The most dramatic evidence of abuse came in the 1930s in the western and midwestern United States. An extended drought, combined with fencerow-to-fencerow planting, spawned one of the most significant environmental disasters of human history: the **dust bowl**. Millions of tons of topsoil were lost from U.S. farms in huge dust storms.

The dust bowl stimulated a rash of conservation efforts to help protect farmland. Perhaps the most significant step was the planting of long rows of trees alongside fields to reduce wind erosion (**FIGURE 5-14**). Today, farmers sometimes leave wheat stubble and residues from crops on the ground over the winter to protect soils. Unfortunately, many of the improvements in soil management made in the immediate
post–dust bowl era are being lost. Many farmers are once again planting from fencerow to fencerow in an effort to increase their output. Not surprisingly, devastating dust storms are becoming more and more common in some states, such as Texas and California.

**KEY CONCEPTS**

The grassland biome occurs in regions of intermediate precipitation—enough to support grasses but not enough to support trees. On most continents, the rich soil of the biome has been heavily exploited by humans for agriculture.

### The Desert Biome

Deserts exist throughout the world. Some cover vast regions. The Sahara, for example, stretches across northern Africa and is about the size of the United States. In North America, deserts exist primarily on the downwind side of mountain ranges.

Deserts, although dry, are not devoid of precipitation (Table 5-1). Rain often comes in violent downpours, however, causing flash flooding and severe erosion that have sculpted the magnificent canyons of the desert Southwest. Many species of desert wildflowers are well adapted to the infrequent but intense spring rains. These species have an accelerated life cycle, in which they grow and produce flowers within a few days of a thunderstorm, turning the desert into a colorful garden almost overnight (FIGURE 5-15).

Plants that live in the desert must also be adapted to tolerate a wide range of temperatures. In the desert, temperatures may reach 50°C (120°F) during the day and then drop to near freezing at night. The temperature in the desert fluctuates so much in large part because of the absence of moisture in the atmosphere, which reduces heat retention by the nighttime sky. Thus, even though the sun warms up the desert floor during the day, the heat escapes quickly at night.

Plants in the desert are adapted to low soil moisture. Many desert plants, such as cacti, have shallow root systems that extend laterally from the plant. Running just below the surface, these roots absorb rain and melted snow and then transport the water to the main body of the plant, where it is stored. Other desert plants, such as the mesquite tree, have deep taproots that extend downward, sometimes over 30 to 60 meters (100 to 200 feet), to moist soil. Taproots anchor the plant and also provide a relatively reliable source of water.

Water absorbed by the roots of many desert plants is stored in succulent, water-retaining tissues, giving the plant an ample supply on which to draw during the rainless months. In most desert plants, water supplies are protected by the presence of thick outer layers and waxy coats that reduce moisture loss.

Desert plants are often widely spaced on the desert floor, which reduces competition for water and ensures an adequate supply. How do plants space themselves? Some plants release growth-inhibiting chemicals into the soil that deter competitors from taking root in a region around them.

The thorns of cacti are yet another adaptation that reduces water loss. Thorns protect cacti from being eaten, but they also give some degree of protection from the sun by providing shade and reflecting some sunlight from the plant (FIGURE 5-16a). White, fluffy hairs found on some species of cacti also reflect sunlight and provide shade (FIGURE 5-16b).

Many insects and other animals also make the desert biome their home. Like the plants, the animals are well adapted to desert conditions. The thick scales of snakes and lizards, for example, minimize water loss, permitting these creatures to thrive in the dry, hot conditions (FIGURE 5-17a). Lizards and other species, such as mice, also survive by avoiding daytime heat. They rest in caves or burrows and venture forth only at night. The ringtail, for example, sleeps all day and comes out at night to find its food (FIGURE 5-17b).

Because water is a rare commodity in the desert, many species acquire the moisture they need from cellular energy production. Water released during this process is called **metabolic water**. In some species, metabolic water provides nearly all of the water needed to survive. The kangaroo rat receives all of the moisture it needs from this process and from the plants and insects it eats. Although cellular energy production does not produce large amounts of water, it can be enough if species possess additional adaptations that help them conserve body water. The kangaroo rat, for example, excretes a highly concentrated urine, a physiologic adaptation to the hot, dry conditions of the desert. Snakes and lizards also excrete a highly concentrated urine that reduces water loss.

Deserts can turn cold. Winter in the desert often brings freezing temperatures and snow for several days and some-
times weeks on end. Thus desert plants must also be able to tolerate cold.

Large cities have sprung up in many of the world’s deserts. To supply inhabitants, food is trucked in from farms hundreds of miles away. Water is often pumped from deep aquifers or is transported from distant sources via extensive pipelines. Phoenix, Arizona, for example, receives much of its water from the Colorado River, several hundred miles to the north-west, through a gigantic (and costly) canal and pipeline.

The continuing expansion of cities in the deserts of the world and the growing water demand have created serious problems, however. Southeast of Phoenix, for instance, over 300 square kilometers (120 square miles) of land has subsided (sunk) more than 2 meters (6 feet) because of intensive groundwater withdrawal. Cracks in the Earth’s surface have developed in subsided areas. Some of the largest cracks are 3 meters (10 feet) wide and 3 meters deep and run for 300 meters (990 feet), three times the length of a football field. Subsidence and cracks in the Earth’s surface can break pipelines and can destroy homes and highways. Depletion of groundwater can also eliminate the supply of water for native plant species.

Each year, millions of acres of new desert form on semiarid grasslands. Research suggests that deserts are expanding principally because of human actions. Livestock overgrazing destroys grasses in semiarid regions. The loss of vegetation may reduce rainfall, creating desertlike conditions. Climate change, both natural and human induced, may also be contributing to the spread of deserts. Stopping desertification will require dramatic improvements in land management, especially grazing, and reductions in greenhouse gases.

**KEY CONCEPTS**

The desert biome is characterized by dry, hot conditions, but often abounds with plants and animals adapted to the heat and lack of moisture. Unfortunately, deserts of the world are expanding as a result of human activities such as overgrazing livestock and the production of greenhouse gases.

**The Tropical Rain Forest Biome**

Heading south to the equator, we find one of the most endangered biomes on Earth, the tropical rain forest (FIGURE 5-18). Tropical rain forests exist near the equator in South and Central America, Africa, and Asia (Figure 5-5). By far the most complex and diverse of all the Earth’s biomes, tropical rain forests support a wealth of plants, animals, and microorganisms. A small tropical island, for example, may have as many butterfly species (500 to 600) as the entire United

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**FIGURE 5-16 The cactus.** (a) Spines protect cacti from hungry animals and also provide shade. (b) Some cacti have white hairs that block the sun.

**FIGURE 5-17 Animals of the desert.** (a) Gila monster and (b) ringtail.
Two hundred fifty different tree species exist in a single hectare (2.5 acres) of rain forest; in the temperate deciduous forest biome of the United States, a similar tract may have 20 to 30 species.

The tropics actually contain a variety of different ecosystems, of which the rain forest is the largest and best known. With 200 to 400 centimeters (60 to 160 inches) of rain falling per year, trees of the tropical rain forest grow to heights of 60 meters (200 feet) or more. The tops of the tallest trees in a tropical rain forest form a dense canopy that blocks much of the incoming sunlight. Shorter trees form a lower canopy that intercepts most of the remaining light. As a result, only about 1% of the incoming sunlight reaches the ground. Because so little light strikes the forest floor, ground-level vegetation is sparse. Only those species adapted to low light (for example, African violets, philodendrons, and ferns) can survive in such conditions. The lack of ground-level vegetation relegates most life to the tree-tops. Dwelling in this zone are monkeys, birds, and countless species of insects.

The tropical rain forest is a paradox to the untrained observer. Although it is the richest and most diverse biome on Earth, most of its soils are thin and nutrient poor. If a section of forest growing on such poor soil is cleared to make room for crops or cattle ranches, it will generally produce for only 4 or 5 years before its nutrients are depleted. Large-scale farming and ranching on many rain forest soils are generally doomed to fail.

An understanding of basic ecology explains the paradox of the tropical rain forest, in which the world’s richest biome grows on some of the world’s poorest soils. To begin, we ask: Why is the soil so poor? In tropical rain forests, dead trees, leaves, and other forms of biomass (dead animals) that fall to the ground are consumed by countless insects. The material that the insects do not eat is rapidly decomposed by bacteria, fungi, and other organisms. Nutrients released into the soil by bacterial decay are quickly absorbed by the roots of trees located just beneath the ground’s surface. Thus, virtually all of the nutrients are locked up in plants and animals. In essence, then, tropical soils are so poor because life is so rich.

The lush vegetation of the tropics protects the soil from erosion. Thus, clearing the land for agriculture can be a chancy proposition. Heavy rainfall in the wet season erodes soils no longer protected by trees and other vegetation, rendering the new farmland useless and choking nearby streams and rivers with sediment. The loss of the thin topsoil also makes recovery from damage more difficult and protracted. Some forestry scientists believe that it could take large forest clearings 500 years or more.

Many rain forest soils are also useless for farming and ranching because they contain large amounts of iron. These soils are called lateritic (LA-ter-it-ick) soils (later is Latin for “brick”). When cleared and exposed to sunlight, lateritic soils bake as hard as bricks. The impenetrable crust that develops 1 to 2 years after clearing makes the soils virtually impossible to cultivate.
Tropical forests are the lungs of the planet. They “breathe in” vast amounts of carbon dioxide and release oxygen vital to animals. By absorbing carbon dioxide, tropical rain forests help reduce global warming, a problem discussed in Chapter 20.

Once covering a region approximately the size of the United States, only about half of the rain forest remains. Despite worldwide concern for the fate of tropical rain forests, timber cutting continues. A U.N. study suggests that tropical deforestation is occurring at a rate of 17 million hectares (42 million acres) per year, an area about the size of the state of Washington. At this rate, the remaining tropical forests will be gone in 100 years—and with them, tens of thousands, perhaps millions, of species. Widespread destruction of tropical forests could upset global rainfall patterns and could affect global climate by reducing the amount of carbon dioxide removed from the atmosphere each year.

Altitudinal biomes mirror the latitudinal biomes described in this chapter and are a reflection of differences in temperature and precipitation. Starting at the top of the mountain, for example, one encounters a cold, treeless region similar to the Arctic tundra. Known as the alpine tundra, this area is characterized by a short growing season and long, cold winters (FIGURE 5-20). But unlike the Arctic tundra, the alpine tundra receives lots of moisture. Most of the precipitation comes in the form of snow, and most blows away, ending up at the next lower level.

Climbing downward, one encounters a band of conifers akin to the taiga. In the Rocky Mountains, this zone borders on grassland. On the west slope of the Cascade Mountains, however, the taiga-like region borders deciduous forests.

Altitudinal Biomes

Temperature and precipitation (rain and snow) profoundly influence life in biomes, affecting species diversity and the abundance of life. The relationship between climate and life is dramatically illustrated in mountainous terrain. If you walked from the top of a mountain to its base, you would very likely progress through several distinct life zones called altitudinal biomes (FIGURE 5-19).

5.3 Aquatic Life Zones

On land, precipitation and temperature are the chief determinants of the distribution and abundance of life. In aquatic life zones, however, water is abundant and temperature relatively constant. The abundance and diversity of life forms are determined principally by energy and nutrients.

Aquatic life zones may be either freshwater or saltwater. In both freshwater and saltwater aquatic life zones, many food chains begin with a group of producer organisms, the phytoplankton (FIE-toe-plank-ton). Phytoplankton are microscopic, free-floating, photosynthetic organisms, mostly algae and diatoms (FIGURE 5-21). These organisms capture solar energy, using it to produce carbohydrates from carbon dioxide dissolved in the water.
Phytoplankton are consumed by microscopic zooplankton (ZOE-oh-plank-ton), single-celled protozoans, and multicellular crustaceans (FIGURE 5-22). Zooplankton form the second trophic level of many aquatic food chains. Zooplankton, in turn, are consumed by small fish, which are a food source for larger fish and other organisms.

**KEY CONCEPTS**

Aquatic systems are divided into distinct regions, known as **aquatic life zones**, which may be freshwater or saltwater. The abundance of life is determined by energy and nutrient levels. Phytoplankton form the base of aquatic food chains.

**Freshwater Lakes**

Freshwater aquatic life zones include lakes, ponds, rivers, and streams. We’ll begin by looking at ponds and lakes.

Ponds are relatively small, shallow bodies of water. Because they are shallow, sunlight often penetrates to the bottom, providing plenty of energy for all aquatic life. Lakes are deeper than ponds and generally contain four distinct zones. The first is the **littoral** (LIT-tore-el) zone, from the Latin word *litoralis*, meaning “seashore” or “coast” (FIGURE 5-23). The littoral zone consists of the shallow waters at the margin of a lake, where rooted vegetation often grows. It contains abundant phytoplankton and rooted vegetation. Some rooted vegetation never breaks the surface; it is submerged throughout its life. Others—for example, cattails—extend above the water’s surface. Still other plants—such as water lilies—have leaves and flowers that float on the water’s surface.

As Figure 5-23 shows, the **limnetic** (limb-NET-tick) zone is a region commonly called “open water.” Extending downward to the point at which light no longer penetrates, the limnetic zone is the main photosynthetic body of a lake. In many lakes, the limnetic zone supports abundant phytoplankton—so many, in fact, that phytoplankton biomass may exceed the biomass of rooted vegetation along the shoreline. The limnetic zone is therefore something of a biological factory, producing the food that supports most other aquatic...
life forms. It is also a major source of oxygen, required by zooplankton, many bacteria, and animals such as fishes.

The **profundal zone** lies beneath the limnetic zone in deeper lakes and extends to the bottom (Figure 5-23). Because no sunlight penetrates the profundal zone, conditions are not favorable for plant and algal growth. Without sunlight and plants, oxygen levels remain fairly low. Fishes can survive in the region, but they rely on food produced in the limnetic and littoral zones.

The bottom of a lake is the **benthic zone** (Figure 5-23). It is home to organisms that tolerate cool temperatures and low oxygen levels—such as snails, clams, crayfish, various aquatic worms, and insect larvae (including those of the mayfly, dragonfly, and damselfly). The larvae emerge during the spring and become free-flying insects. Mayflies, for example, generally breed within a day of emergence and then die. Many of them are eaten by fish and are therefore an important source of food in freshwater aquatic ecosystems.

**KEY CONCEPTS**

Lakes are divided into four regions—the littoral zone, the limnetic zone, the profundal zone, and the benthic zone—with very different conditions and, consequently, very different life forms.

**Lake Turnover** During the summer in temperate climates (such as North America), the water of most lakes forms three distinct layers characterized by different temperatures (Figure 5-24). The warm surface water of a lake is called the **epilimnion** (ep-eh-LIM-knee-on) (Figure 5-24a). Just beneath the epilimnion is a region of abrupt temperature change, the **thermocline** (thur-moe-CLINE). Swimmers can experience the thermocline by diving toward the bottom of a lake. Below the thermocline is a region of fairly uniform temperature, the **hypolimnion** (high-poe-LIM-knee-on). In the summer, the hypolimnion contains dense, cold water.

As Figure 5-24a shows, the three summertime layers also differ in oxygen levels. The oxygen concentration is highest in the epilimnion, where light penetration and photosynthesis are greatest, and falls rather rapidly from the surface to the bottom as photosynthesis declines.

The thermal layering of lakes is not static. During the fall, for example, the surface waters gradually cool, and the water temperature of a lake eventually becomes fairly uniform from top to bottom (Figure 5-24b). In other words, thermal stratification disappears. In the fall, winds often churn the water, causing a thorough mixing of surface and deep water. As a result, oxygen levels also become fairly uniform from top to bottom. This mixing of surface and bottom waters is known as the **fall overturn**.

In late fall and early winter, the surface waters of a lake cool even more. Ice may form on the lake, often covering the entire surface. Because ice is less dense than liquid water, it floats; this leaves an ice-free zone in deeper lakes, where fish live. At this time, water oxygen levels are fairly uniform from top to bottom, although levels are lowest in the deepest waters and at the bottom (Figure 5-24c).

During the winter, many species such as turtles burrow in the mud, where they hibernate. Fishes, however, remain active and continue to feed throughout the winter, living on oxygen produced during the summer months. Fortunately, cold water reduces their metabolism and thus their demand for oxygen. Algae, which are present in reduced number, replenish the oxygen so long as sunlight can penetrate the ice.

In the spring the ice melts, and the water temperature becomes uniform once again. Winds agitate the water, causing a mixing known as the **spring overturn** (Figure 5-24d). As the days get longer and warmer, however, the surface waters begin to warm, and the lake again becomes thermally stratified.

**Rivers and Streams**

Rivers and streams are complex ecosystems. As with lakes, no two streams are alike. In many areas, streams begin in mountains or hilly terrain, collecting water that falls to the Earth as rain or snow. The region drained by a stream is called a **watershed**. Small streams join to form rivers, and rivers flow downhill to the sea.

Streams and rivers are generally well oxygenated because they have a relatively large surface area (relative to their water volume) to absorb oxygen from the air. Current also facilitates oxygenation. Current velocity is determined by the gradient—that is, the steepness of the terrain. Fast-moving currents of mountain streams produce waves and rapids as the water collides with rocks or drops over ledges. This agitation greatly increases oxygenation. For these and other reasons, photosynthesis is a less important source of oxygen in rivers and streams than it is in ponds and lakes. Certain fish are adapted to
different currents. Trout, for example, generally inhabit cold, oxygen-rich mountain streams where the current is quite rapid. Black bass live in rivers, where the waters are warmer, less oxygenated, and slower.

Unlike many lakes and ponds and terrestrial biomes, streams are rather open ecosystems; that is, they receive a great many nutrients from bordering ecosystems. In some streams, much of the biologically available energy actually comes from nearby terrestrial vegetation, such as leaves that fall into the stream. Animal feces, insects, stems, nuts, and other biomass may also be washed into streams during rainstorms. All of this material feeds the aquatic food web. Many primary consumers in streams, therefore, are detritivores—organisms that feed on waste or remains of plants and animals (detritus). Streams do have their own producers, mostly algae and rooted vegetation, but in some cases, these organisms play only a minor role in providing food.

**KEY CONCEPTS**

Rivers and streams are complex ecosystems that rely more on agitation for oxygenation of their waters than lakes do. Many nutrients in streams that support aquatic life come from neighboring terrestrial ecosystems. The quality of water in a stream is profoundly influenced by activities in the watershed.
Protecting Freshwater Ecosystems

Lakes are repositories for pollutants and are highly vulnerable to them, especially if their waters are replaced slowly. Streams generally fare better than lakes because of their flow, which tends to whisk pollutants away. Despite this natural purging, streams and rivers are also quite vulnerable to pollutants from human sources if those sources are numerous. The Rhine River of Europe, for example, once supported 150 species of fishes. Today, only about 15 species remain, in large part because of pollutants from the hundreds of factories, towns, farms, and sewage treatment plants dotting its banks in the seven countries through which it flows.

Protecting rivers and streams requires measures to control pollution, that is, to reduce the release of pollutants into water bodies. One way they are achieving this goal is by waste minimization. Waste minimization, or waste reduction, involves measures that greatly reduce or eliminate waste. Waste minimization is a preventive measure with great benefit to people and the planet. Many companies are finding that simple, often inexpensive changes in their manufacturing processes will eliminate the need for toxic chemicals—or greatly reduce the output of them. Where there is no waste, there is no need for waste treatment. Waste minimization, therefore, can save companies enormous amounts of money in waste treatment and disposal costs, and it eliminates future liability for harm done by pollution. Spotlight on Sustainable Development 5-1 shows ways Christmas tree farmers can reduce pollutants.

Saltwater Life Zones

The oceans cover over 70% of the Earth’s surface. Like freshwater systems, the ocean can be divided into ecologically distinct life zones. The sections that follow discuss several of the most important ones. In the ocean, as in all other bodies of water, the distribution and abundance of life are dependent on many factors, but the most important are energy and nutrients.

The Coastal Life Zones

The ocean can be crudely divided into two groups of life zones, those lying near the coasts (the coastal life zones) and those of the deeper ocean. We begin our exploration of the seas by examining three coastal life zones: estuaries, seashores, and coral reefs.

KEY CONCEPTS

Like lakes and ponds, streams are self-purging, but are extremely vulnerable to pollution if sources exceed the capacity to self-cleanse.

ESTUARIES AND COASTAL WETLANDS: THE ESTUARINE ZONE

Estuaries are the mouths of rivers, places where freshwater mixes with saltwater. Estuaries are very rich life zones because streams and rivers transport many nutrients from the land and incoming tides carry nutrients into them from the ocean. These nutrients support abundant plant and algal growth and sizable populations of fish and molluscs (clams, oysters, and scallops).

Most estuaries are located near coastal wetlands—saltmarshes, mangrove swamps, and mud flats (FIGURE 5-25). Together, estuaries and coastal wetlands form the estuarine zone. For most people, coastal wetlands are seen as muddy, smelly places of little value. However, studies show that approximately two-thirds of the world’s commercially valuable fishes and molluscs (shellfish) depend on the estuarine zones at some point in their life cycle. For example, many marine fishes spawn in the estuarine zone. Their eggs are laid on the bottom and are extremely susceptible to the deposition of sediment. The larvae that hatch from the eggs feed off phytoplankton and zooplankton that flourish in the nutrient-rich waters of the estuary. The estuarine zone also provides food, shelter, and breeding grounds for millions of waterfowl and fur-bearing animals such as muskrats.

Unfortunately, the estuarine zone is one of the most altered ecosystems on Earth. Dams built on rivers—to control flooding, supply drinking or irrigation water, or provide recreational activities—reduce the flow of freshwater into estuaries. Reservoirs behind dams also capture sediment that would otherwise travel to the estuary. Sediment contains many nutrients vital to estuarine phytoplankton. Dams, therefore, literally starve the organisms at the base of the estuarine food chain.

FIGURE 5-25 Coastal wetland. Aerial view of an estuary and mangrove swamp.
KEY CONCEPTS

The Shoreline  The Earth’s coastlines are generally rocky or sandy regions that support a variety of specially adapted organisms. Abundant sunlight and nutrients account for much of the biological diversity in this zone. Rocky coastlines are home to seaweed (algae), sea urchins, barnacles, and sea stars (FIGURE 5-26). Many of these organisms anchor themselves to the rocks and are thus able to withstand estuarine conditions.

Estuaries are nutrient-rich zones at the mouths of rivers, often associated with coastal wetlands, together forming the estuarine zone. The estuarine zone is highly productive and of great value to humans and other species. Human activities severely threaten this important biological asset.

5-1 Dreaming of a Green Christmas

Each year, Americans buy slightly more than 28 million Christmas trees, which are grown on tree farms throughout the country. They are worth slightly more than $1 billion. Trees are grown in fields cleared from native forest (FIGURE 1). Although the industry helps to boost many local economies, tree farms displace native wildlife. Because of the heavy use of chemical pesticides, they can also threaten waterways and species, including humans, living nearby.

In 1992, residents of Boone, North Carolina, in the Appalachian Mountains, found that the heavy use of chemicals to control both insects and weeds on local Christmas tree farms might be seeping into local water supplies and might also be linked to an elevated rate of childhood leukemia in the region. Although health officials could not say with certainty that there was a correlation between pesticide use and leukemia, hundreds of farmers in Watauga County decided to take action—drastically slashing the amount of pesticide they used. In some instances, farmers were able to eliminate certain pesticides.

Weeds and pests still persist, but they’re being controlled by natural biological control methods. The results have been encouraging. Groundwater supplies are improving. Wildlife are rebounding in fields and nearby woodlands and streams. One local tree farmer noted that he’s seen more wildlife in the last 5 years than he saw 30 years ago.

This effort to help improve both human and environmental health was successful partly because the county agricultural extension office developed a series of workshops for local farmers who wanted to learn alternative ways of controlling pests. Some solutions have been quite simple. In years past, farmers sprayed fields with diazinon or chlordane to kill grubs that dine on the roots of fir trees. Wooly aphids, another pest, were controlled with yet another potent pesticide.

To control weeds, farmers sprayed fields in the late winter with herbicides. This wipes out weeds before they sprout. They then mowed the grass around the trees. It turns out, however, that grubs prefer short grass for laying eggs. Today, many farmers are forgoing the early herbicide treatment and letting the grass grow longer. Grubs have been effectively controlled. Farmers save on mowing costs and herbicide use.

The impact of dams is aptly illustrated by the Aswan High Dam, built in the early 1960s on the Nile River in Egypt to provide irrigation water for farms. Although the dam provides many benefits, it has nearly halted the flow of nutrients into the river’s estuary. This in turn caused a collapse in the sardine fishery in the Mediterranean Sea, as phytoplankton perished. The commercial sardine catch in the Mediterranean dropped from 18,000 tons per year before the dam was built to about 500 tons per year today.

Coastal wetlands have been drained and filled with dirt to build homes, highways, recreational facilities, and factories. These activities destroy habitat for fish and other species. In the United States, over 40% of the coastal wetlands have been destroyed. In California, an estimated 90% have been destroyed.

FIGURE 1 Tree farm in North Carolina.
turbulence generated by waves. Organisms that do not attach themselves, such as sea urchins, live in rocky crevices protected from water currents.

The coastline is also home to a variety of shorebirds that dine on insects, crustaceans, and other organisms. In addition, the coastlines serve as nesting sites for turtles and are home to breeding colonies of seals and walruses. Popular recreation and building sites, many of the world’s coastlines have been severely altered. Turtle nesting sites have been destroyed in many places. Protecting the coastlines from offshore oil spills and human encroachment is extremely important.

Coral Reefs

Coral reefs are the aquatic equivalent of the tropical rain forest. They are home to a dazzling variety of organisms, many of which are colorful beyond imagination (FIGURE 5-28). Like estuaries and coastal wetlands, coral reefs are also highly vulnerable and experiencing considerable damage. Ships running aground on the coral reefs of Florida, for example, are damaging these fragile structures. Each year, thousands of divers visit these coral reefs. Careless divers break delicate coral with their swim fins. Over the years, many of the most popular reefs have been severely damaged.

Sediment is a particularly troublesome pollutant in coral reefs. It clouds seawater, which reduces photosynthesis in a group of microscopic organisms (called dinoflagellates) that live in a mutualistic relationship with many species of corals. Decreasing photosynthesis decreases the amount of food available to coral, and reefs grow more slowly. Particularly heavy sedimentation can bury a reef, choking the life out of it. Several large reefs near Honolulu, in fact, have been destroyed by sediment washed from construction sites, highways, and farms. Housing development on the Florida Keys is also increasing sedimentation, threatening nearby coral reefs. Many of the world’s coral reefs are dead or dying as a result of warming ocean waters thought to be associated with global climate change brought on by human activities.

The Marine Ecosystem

FIGURE 5-29 shows a cross-section of the ocean floor. As illustrated, the ocean floor slopes downward away from landmasses and then drops more steeply. The gradually sloping region is called the continental shelf. The more steeply falling region is the continental slope, and the bottom of the deep ocean is called the abyssal plain.

As Figure 5-29 shows, the ocean is divided into four ecologically distinct life zones: the neritic, euphotic, bathyal, and abyssal. The neritic (neh-RIT-ick) zone is equivalent to the littoral zone of lakes and lies above the continental shelf, which varies in width from 10 to 200 miles away from dry land. The neritic zone contains relatively shallow...
Low tide  
Sunlight  
High tide  
Euphotic zone  
1. Sunlit  
2. Active photosynthesis  
3. Oxygen level high  
4. Nutrient level low  
5. Represents 90% of ocean surface but produces only 10% of commercial fish taken each year  

Abyssal zone  
1. Pitch dark  
2. No photosynthesis  
3. No producers  
4. Little oxygen  
5. Very cold water  
6. Contains 98% of ocean’s species  
7. Animals are either predators or scavengers  
8. Many animals have bioluminescent organs  
9. Decomposer bacteria feed on organic matter on ocean bottom  
10. High water pressure  
11. High in nutrients on ocean floor  

FIGURE 5-28 Coral reef inhabitants. (a) Coral reefs house some of the most spectacular fish known to science. (b) Brightly colored anemones filter food from the water.  

FIGURE 5-29 Ocean zones.  

(a)  
(b)
water and consequently receives abundant sunshine. Its waters are relatively warm and well oxygenated.

Nutrients in the neritic zone come from streams and rivers that flow into the ocean. They are also supplied by upwelling, the transport of nutrient-rich water from the floor of the ocean up the continental slope. These nutrients, which had been deposited from shallower water above, support abundant phytoplankton, zooplankton, and fishes.

In the neritic zone, sunlight normally penetrates to the ocean bottom. Ample sunlight supports large populations of algae and rooted plants, which, in turn, support a great many other species. In fact, most commercial fishing operations in the ocean concentrate their operations in the neritic zone.

The euphotic or photic (you-FO-tic or FO-tic) zone is the oceanic equivalent of the limnetic zone of lakes. It is the open-water region that extends to the lower limits of sunlight penetration, or about 200 meters (650 feet) below the ocean's surface. Abundant sunlight supports numerous species of phytoplankton, including diatoms, dinoflagellates, and others. Phytoplankton support a variety of zooplankton, mostly minute crustaceans.

Phytoplankton also produce plenty of oxygen. Given the high levels of oxygen and ample supply of sunlight, one might think that the euphotic zone would be extremely productive. Unfortunately, the waters are not very rich in nutrients, and the zone is therefore not very productive. Thus, even though the euphotic zone covers 90% of the ocean's surface, it produces only about 10% of the commercial fish taken each year.

Beneath the euphotic zone is a region of semidarkness, the bathyal (BATH-ee-el) zone. The bathyal zone is too dark to support photosynthesis. It is therefore characterized by a lack of photosynthetic organisms and low oxygen levels. Despite these factors, the bathyal zone is home to a variety of fish and other organisms, such as shrimp and squid, which feed on organisms “raining down” from above.

Beneath the bathyal zone is the abyssal (ah-BISS-el) zone is a region of complete darkness. It contains no photosynthetic organisms and is characterized by low oxygen levels. Most animals that live there are either predators or scavengers. To live in this zone, an animal must be adapted to extremely cold water, high water pressure, low oxygen, and complete darkness.

Sediment in the abyssal zone is often rich in nutrients. The deep-ocean floor is populated by a variety of bizarre-looking creatures that make use of these nutrients. Some species of fishes have evolved luminescent organs that shine in the dark, presumably helping them attract food and mates.

**KEY CONCEPTS**

The marine ecosystem consists of four ecologically distinct life zones, similar to those found in lakes.

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**Nature’s laws affirm instead of prohibit.**

*If you violate her laws you are your own prosecuting attorney, judge, jury and hangman.*

—Luther Burbank

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**CRITICAL THINKING**

**Exercise Analysis**

Scientists have asked many questions about these studies. First, could the differences in ice thickness have been the result of normal variation? (Possibly.) Were the measurements of the two submarines taken during the same time of year? (No.) Did the submarines follow the same path? (Actually, they followed slightly different routes.) Could winds have altered ice buildup between the two periods? (Possibly. Winds do alter ice buildup.) Have other studies shown thinning? (Yes. A study of ice measurements by two submarines on a virtually identical route across the Canada Basin during 1958 and 1970 showed that the mean ice cover was thinner in 1970 by 0.69 meter, about 2 feet.)

What other information/data might be useful in analyzing the hypothesis that the world’s polar ice caps are shrinking? One bit of information that would be very helpful would be the extent of the ice sheets—that is, the square kilometers of ice sheet, plotted over time. Recent studies of this phenomenon show a marked decrease in the extent of the Arctic ice sheet, valuable habitat of the polar bear.
CRITICAL THINKING AND CONCEPT REVIEW
1. What is a biome? Why is one biome so different from another? Give some examples.
2. Using what you have learned in the book, and especially the last two chapters, critically analyze the following comment. “Environmentalists speak about ecosystems as being fragile; yet look at the tundra. The conditions there are as harsh as any on Earth.”
3. Design an experiment to determine how long it would take for the Arctic tundra to recover from human impact caused by truck traffic on the unproctected vegetation.
4. Animals are generally well adapted to the biome in which they live. Give some examples of plants and animals and their adaptations.
5. Explain why there are regional differences in vegetation and animal life within a biome.
6. Which biome do you live in? Describe it. How has it been altered?
7. List the pros and cons of oil development in the ANWR. Which side do you take on the issue? Why?
8. Critically analyze the following comment. “The United States has created a rich agricultural industry by plowing grasslands and clearing and plowing temperate forests. There is no reason to believe that countries in the tropics can’t follow the same example. The rain forests are, after all, the richest terrestrial biome known to science.”
9. Why do many deserts form downwind from mountain ranges?
10. Explain why the desert biome is spreading.
11. What are the primary determinants of species composition and abundance in terrestrial and aquatic habitats?
12. Describe each of the four zones of a lake (littoral, limnetic, profundal, and benthic) in terms of light availability, nutrient levels, oxygen concentration, and life forms.
13. Describe thermal stratification in deep lakes. Why does it occur during the summer but disappear throughout most of the rest of the year?
14. Why is the current so important in determining the abundance and type of life in a river?
15. Explain how streams and rivers recover from pollution and why natural recovery methods are so often overwhelmed.
16. What is an upwelling? How is it similar to an estuary? How is it different?
17. Describe ways in which human activities affect coral reefs and the estuarine zone.

KEY TERMS
abyssal plain
abyssal zone
alpine tundra
altitudinal biomes
aquatic life zones
bathyal zone
benthic zone
climate
coastal wetlands
conifers
continental shelf
continental slope
coral reef
Coriolis effect
deciduous trees
dust bowl
El Niño
epilimnion
estuarine zone
estuaries
euphotic (or photic) zone
fall overturn
grasses
hypolimnion
lateritic soil
limnetic zone
littoral zone
neritic zone
northern coniferous forest biome
permafrost
phytoplankton
polar easterlies
piles
profundal zone
shortgrass prairie
spring overturn
taiga
tallgrass prairie
temperate zones
thermocline
trade winds
tropics
tundra
upwellings
waste minimization
waste reduction
watershed
weather
westerlies
zooplankton

REFERENCES AND FURTHER READING
To save on paper and allow for updates, additional reading recommendations and the list of sources for the information discussed in this chapter are available at http://environment.jbpub.com/9e/.

Connect to this book’s website: http://environment.jbpub.com/9e/
The site features eLearning, an online review area that provides quizzes, chapter outlines, and other tools to help you study for your class. You can also follow useful links for in-depth information, research the differing views in the Point/Counterpoints, or keep up on the latest environmental news.