Other competition occurs underground, where the roots compete for soil water and plant nutrients.

Interactions between plants and animals and competition both within and among animal species also have significant effects on the nature of an ecosystem. Animals are often helpful to plants during pollination or the dispersal of seeds, and plants are the basic food supply for many animals. The simple act of grazing may help determine the species that make up a plant community. During dry periods, herbivores may be forced to graze an area more closely than usual, with the result that the taller plants are quickly grazed out. Plants that grow close to the ground, that are unpalatable, or that have the strongest root development are the ones that survive. Hence, grazing is a part of the natural selection process, but serious overgrazing rarely results under natural conditions because wild animal populations increase or decrease with the available food supply. To be more precise, the number of animals of a given species will fluctuate between the maximum number that can be supported when its food supply is greatest and the minimum number required for reproduction of the species. For most animals, predators are also an important control of numbers. Fortunately, when the predator’s favorite species is scarce, it will seek an alternative species for its food supply.

Human Impact on Ecosystems

Throughout human history, we have modified the natural development of ecosystems. Except in regions too remote to be altered significantly by civilization, humans have eliminated much of Earth’s natural vegetation. Farming, fire, grazing of domesticated animals, deforestation and afforestation, road building, urban development, dam building and irrigation, raising and lowering of water tables, mining, and the filling in or draining of wetlands are just a few ways in which humans have modified the plant communities around them. Overgrazing by domesticated animals can seriously harm marginal environments in semiarid climates. Trampling and compaction of the soil by grazing herbivores may reduce the soil’s ability to absorb moisture, leading to increased surface runoff of precipitation. In turn, the decreased absorption and increased runoff may respectively lead to land degradation and gully erosion.

It should be noted that ecosystems are not the only victims as humans alter natural environments; the changes can often produce long-term negative effects on humans themselves.

The desertification of large tracts of semiarid portions of East Africa has resulted periodically in widespread famine in countries such as Ethiopia and Somalia (Fig. 11.21). Elsewhere, the continuing destruction of wetlands not only eliminates valuable plant and animal communities but also often seriously threatens the quality and reliability of the water supplies for the people who drained the land.

We have in fact so changed the vegetation in some parts of the world that we can characterize classes of cultivated vegetation cared for by humans—for example, flowers, shrubs, and grasses to decorate our living areas and grains, vegetables, and fruits that we raise for our own food and to feed the animals that we eat. Our focus in the remainder of this chapter, however, is on the major ecosystems of Earth as we assume they would appear without human modification. Human impact upon and adaptation to the various vegetation types are described in more detail along with the appropriate climate types in Chapters 9 and 10.

Classification of Terrestrial Ecosystems

Classifying the geography of plant communities is no easy task, as their distribution is a complex phenomenon influenced by a variety of factors. However, plant communities are among the most visible of natural phenomena, so they can be easily observed and categorized on the basis of form and structure. Of course, the composition of the natural vegetation changes from place to place.
Exotic species are plants or animals that have been introduced to a new environment from where they originated, usually by human activities. Some exotics are regarded as beneficial; many landscaping plants used in North America were brought in from other continents or regions and planted as decorative foliage. Problems have occurred, however, with many other exotics, introduced either purposefully or inadvertently, that have adapted to their new environment to the detriment of the native plants or animals. If the exotic is unable to adapt to its new home, then it dies off and will not be a problem. Many exotics, however, thrive at the expense of native populations. One example of a destructive and harmful exotic is the imported red fire ant, which causes a painful bite and kills off many native insect and other populations (often beneficial insects) in the areas they invade. Fire ants came to the United States in the 1930s from Brazil, as “hitchhikers” on a ship that docked at Mobile, Alabama. Since that time, the geographic distribution of fire ant colonies has been closely documented as they have spread throughout the southern states from their point of introduction.

A map of the expansion of fire ants outward from this location illustrates the rapid impact that the introduction of a species to a new environment can have. This spread of fire ants is an example of spatial diffusion—the expansion of a distribution over an area. Climatic factors will influence or limit the eventual distribution of fire ant populations in the United States, but as of now they are still expanding their geographic range. Cold to the north and aridity to the west are the limiting environmental factors, but these ants also have been discovered in Southern California and in settled areas of the arid West, where lawn or agricultural irrigation provides adequate moisture for their survival. The fire ants may have been spread to these locations by potted nursery plants or turf grasses shipped in from areas already infested with this pest.
in a transitional manner, just as temperature and rainfall do, and although distinctly different types are apparent, there may be broad transition zones (ecotones) between them. Nevertheless, over the world there are distinctive recurring plant communities, indicating a consistent botanical response to systematic controls that are essentially climatic. It is the dominant vegetation of these plant communities that we recognize when we classify Earth’s major terrestrial ecosystems (biomes).

All of Earth’s terrestrial ecosystems can be categorized into one of four easily recognized types: forest, grassland, desert, and tundra (Figs. 11.22a, 11.22b, 11.22c, and 11.22d). Because vegetation adapted to cold climates may occur not only in high-latitude regions but also at high elevations at any latitude, biogeographers often refer to the last of the major types as arctic and alpine tundra. However, the forests of the equatorial lowlands are an entirely different world from those of Siberia or of New England, and the original grasslands of Kansas bore little resemblance to those of the Sudan or Kenya. Hence, the four major types of ecosystems can be subdivided into distinctive biomes, each of which is an association of plants and animals of many different species. Pure stands of particular trees, shrubs, or even grasses are extremely rare and are limited to small areas having peculiar soil or drainage conditions.

Earth’s major biomes are mapped in Figure 11.23 on the basis of the dominant associations of natural vegetation that give each its distinctive character and appearance. The direct influence of climate on the distribution of these biomes is immediately apparent. Temperature (or latitudinal effect on temperature and insolation) and the availability of moisture are the key factors in determining the location of major biomes on the world scale (Fig. 11.24). Because climatic elements are those that affect vegetation the most, detailed descriptions of major vegetation types are discussed with their corresponding climate types found in Chapters 9 and 10.

Forest Biomes

Forests are easily recognized as associations of large, woody, perennial tree species, generally several times the height of a human, and with a more or less closed canopy of leaves overhead. They vary enormously in density and physical appearance. Some are evergreen and either needle- or broad-leaf; others are deciduous, dropping their leaves to reduce moisture losses during dry seasons or when soil water is frozen. Forests are found only where the annual moisture balance is positive—where moisture availability considerably exceeds potential evapotranspiration in the growing season. Thus, they occur in the tropics, where either the ITCZ (intertropical convergence zone) or the monsoonal circulation brings plentiful rainfall, and in the middle latitudes, where precipitation is associated with cyclones along the polar front, with summer convectional rainfall, or with orographic uplift.

Tropical and middle-latitude forests have evolved different characteristics in response to the nature of the physical limitations in each area. In general, tropical forests have developed in less restrictive forest environments. Temperatures are always high, though not extreme, in the humid tropics, encouraging rapid and luxuriant growth. Middle-latitude forests, on the other hand, must adapt to combat either seasonal cold (ranging from occasional frosts to subzero temperatures) or seasonal drought (which may occur at the worst possible time for vegetative processes).

Tropical Forests

The forests of the tropics are far from uniform in appearance and composition. They grade poleward from the equatorial rainforests, which support Earth’s greatest biomass, to the last scattering of low trees that overlook seemingly endless expanses of tall grass or desert shrubs on the tropical margins. We have subdivided the tropical forests into three distinct biomes: the tropical rainforest, the monsoon rainforest, and other tropical forest types, primarily thornbush and scrub. Of course, there are gradations (ecotones) between the different types, as well as distinctive variations that are found in individual localities only.

Tropical Rainforest

In the equatorial lowlands dominated by Köppen’s tropical rainforest climate, the only physical limitation for vegetation growth is competition between adjacent species. The competition is for light. Temperatures are high enough to promote constant growth, and water is always sufficient. Thus, we find forests consisting of an amazing number of broad-leaf evergreen tree species of rather similar appearance because special adaptations are not required. A cross section of the forest often reveals concentrations of leaf canopies at several different levels. The trees composing the distinctive individual tiers have similar light requirements—lower than those of the higher tiers but higher than those of the lower tiers (Fig. 11.25). Little or no sunlight reaches the forest floor, which may support ferns but is often rather sparsely vegetated. The forest is literally bound together by vines, lianas, which climb the trunks of the forest trees and intertwine in the canopy in their own search for light. Aerial plants may cover the limbs of the forest giants, deriving nutrients from the water and the plant debris that falls from higher levels. Light and variable wind conditions in the rainforest (associated with the tropical belt of the doldrums) preclude wind from being an effective agent of seed and pollen dispersal, so large colorful fruits and flowers, designed to attract animals that will unwittingly carry out seed and pollen dispersal, prevail.

The forest trees commonly depend on widely flared or buttressed bases for support because their root systems are shallow. This is a consequence of the richness of the surface soil and the poverty of its lower levels. The rainforest vegetation and soil are intimately associated. The forest litter is quickly decomposed, its nutrients released and almost immediately reabsorbed by the forest root systems, which consequently remain near the surface. In this way, a rainforest biomass and the available soil nutrients maintain an almost closed system. Tropical soils that maintain the amazing biomass of the rainforest are fertile only as long as the forest remains undisturbed. Clearing the forest interrupts the crucial cycling of nutrients between the vegetation and the soil; the copious amounts of water percolating through the soil leach away its soluble constituents, leaving behind only inert iron and aluminum...
**FIGURE 11.22**
The four major types of Earth biomes: (a) forest biome near Dornbirn, Austria; (b) grassland biome in Paraguay; (c) desert biome in Big Bend National Park, Texas; (d) tundra biome in coastal Greenland.

Which one of these images shows an excellent outcome of an ecotone?
Tropical Rainforest (includes Monsoon Forest)
Other Tropical Forest
Mediterranean Middle-Latitude Forest
Broad-Leaf and Mixed Middle-Latitude Forest
Coniferous Forest
Tropical Grassland
Middle-Latitude and Border Tropical Grassland
Tundra and Alpine Meadow
Desert Vegetation
Little or No Vegetation

**FIGURE 11.23**
World map of natural vegetation.
A Western Paragraphic Projection developed at Western Illinois University
moist air onshore along tropical coasts. The wet monsoon season rainfall may be very high, even hundreds of centimeters where air is forced upward by topographic barriers. In any case, it is sufficient to produce a forest that, once established, remains despite the dry monsoon season. Monsoon forests may have discernible tiers of vegetation related to the varying light demands of different species, and they are included with the tropical rainforest in Figure 11.23. However, the number of species is less than in the true rainforest, and the overall height and density of vegetation are also somewhat less. Some of the species are evergreen, but many are deciduous.

Other Tropical Forests, Thornbush, and Scrub
Where seasonal drought has precluded the development of true rainforest or where soil characteristics prevent the growth of such vegetation, variant types of tropical forests have developed. These tend to be found on the subtropical margins of the rainforests and on old plateau surfaces where soils are especially poor in nutrients. The vegetation included in this category varies enormously but is generally low growing in comparison to rainforest, without any semblance of a tiered structure, and is denser at ground level. It is commonly thorny, indicating defensive adaptation against browsing animals, and it shows resistance to drought in that it is generally deciduous, dropping its leaves to conserve moisture during the dry winter season. Ordinarily, grass is present beneath the trees and shrubs. As we move away from the equatorial zone, we find the trees more widely spaced and the

Monsoon Rainforest
In areas of monsoonal circulation, there is an alternation between the dry monsoon season, when the dominant flow of air is from the land to the sea, and the wet monsoon season, when the atmospheric circulation reverses, bringing

![Figure 11.24](image-url)  
**Figure 11.24**  
This schematic diagram shows distribution of Earth’s major biomes as they are related to temperature (latitude) and the availability of moisture. Within the tropics and middle latitudes, there are distinctly different biomes as total biomass decreases with decreasing precipitation. **What major biome dominates the wetter margins of all latitudes but the Arctic?**

![Figure 11.25](image-url)  
**Figure 11.25**  
A tropical rainforest on the island of St. Croix, U.S. Virgin Islands. The dense nature of the forest canopy effectively conceals the vast number of different evergreen tree species and relatively open forest floor. **How might this rainforest differ from the rainforests of the Pacific Northwest of the United States?**
grassy areas becoming dominant. Along tropical coastlines, a specially adapted plant community, known as mangrove, thrives (see again Fig. 11.16). Here trees are able to grow in salt water.

**Middle-Latitude Forests**

The forest biomes of the middle latitudes differ from those of the tropics because the dominant trees have evolved mechanisms to withstand periods of water deprivation due to low temperatures and annual variations in precipitation. Evergreen and deciduous plants are present, equipped to cope with seasonal extremes not encountered in tropical latitudes.

**Mediterranean Sclerophyllous Woodland** Surrounding the Mediterranean Sea and on the southwest coasts of the continents between approximately 30° and 40°N and S latitude, we have seen that a distinctive climate exists—Köppen’s mesothermal hot- and dry-summer type (Mediterranean). Here annual temperature variations are moderate, and freezing temperatures are rare. However, little or no rainfall occurs during the warmest months, and plants must be drought resistant. This requirement has resulted in the evolution of distinctive vegetation that is relatively low growing, with small, hard-surfaced leaves and roots that probe deeply for water. The leaves must be capable of photosynthesis with minimum transpiration of moisture. The general look of the vegetation is a thick scrub plant community, called chaparral in the western United States and maquis in the Mediterranean region (see again Fig. 10.3). Wherever moisture is concentrated in depressions or on the cooler north-facing hill slopes, deciduous and evergreen oaks occur in groves (Fig. 11.26). Drought-resistant needle-leaf trees, especially pines, are also part of the overall vegetation association. Thus, the vegetation is a mosaic related to site characteristics and microclimate. Nevertheless, the similarity of the natural vegetative cover in such widely separated areas as Spain, Turkey, and California is astonishing. (Note the location of Mediterranean middle-latitude forest, Fig. 11.23.)

**Broad-Leaf Deciduous Forest** The humid regions of the middle latitudes experience a seasonal rhythm dominated by warm tropical air in the summer and invasions of cold polar air in the winter. To avoid frost damage during the colder winters and to survive periods of total moisture deprivation when the ground is frozen, trees whose leaves have large transpiring surfaces drop these leaves and become dormant, coming to life and producing new leaves only when the danger period is past. A large variety of trees have evolved this mechanism; certain oaks, hickory, chestnut, beech, and maples are common examples. The seasonal rhythms produce some beautiful scenes, particularly during the periods of transition between dormancy and activity, with the spraying of new leaves in the spring and the brilliant coloration of the fall as chemical substances draw back into the plant for winter storage (Fig. 11.27).

The trees of the deciduous forest may be almost as tall as those of the tropical rainforests and, like them, produce a closed canopy of leaves overhead or, in the cold season, an interlaced network of bare branches. However, lacking a multistoried structure and having lower density as a whole, the middle-latitude deciduous forests allow much more light to reach ground level. Forests of this type are the natural vegetation in much of western Europe, eastern Asia, and eastern North America. To the north and south, they merge with mixed forests composed of broad-leaf deciduous trees and conifers. (Broad-leaf forests and mixed forests are combined in Fig. 11.23.) Both the broad-leaf deciduous and mixed forests have been largely logged off or cleared for agricultural land, and the original vegetation of these regions is rarely seen.

**Broad-Leaf Evergreen Forest** Beyond the tropics, broad-leaf evergreen forests, where the trees remain active throughout the year, are mainly found in certain Southern Hemisphere locations. Here the mild maritime influence is strong enough to prevent either dangerous seasonal droughts or severely low winter temperatures. Southeastern Australia and portions of New Zealand, South Africa, and southern Chile are the principal areas of this type. In the Northern Hemisphere, broad-leaf evergreen forest may once have been significant in eastern Asia, but it has long since been cleared for cultivation. Limited areas occur in the United States in Florida and along the Gulf Coast as a belt of evergreen oaks and magnolias.

**Mixed Forest** Poleward and equatorward, the broad-leaf deciduous forests in North America, Europe, and Asia gradually merge into mixed forests, including needle-leaf coniferous trees, normally pines. In general, where conditions permit the growth of broad-leaf deciduous trees, coniferous trees cannot compete successfully with them. Thus, in mixed forests, the conifers, which are actually more adaptable to soil and moisture deficiencies, are found in the less hospitable sites: in sandy areas, on acid soils, or where the soil itself is thin. The northern mixed forests reflect the transition to colder climates with increasing latitude; eventually, conifers become dominant in this direction. The southern mixed forests are more problematic in origin. In the United States, they are transitional to pine forests situated on sandy soils of the coastal plain. In Eurasia, they coincide with highlands dominated by conifers during a stage.
cies can tolerate conditions of physiologic drought (unavailability of moisture because of excessive soil permeability, a dry season, or frozen soil water) without defoliation. Pines, in particular, also demand little from the soil in the form of soluble plant nutrients, especially basic elements such as calcium, magnesium, sodium, and potassium. Thus, they grow in sandy places and where the soil is acid in character. As a whole, conifers are particularly well adapted to regions having long, severe winters combined with summers warm enough for vigorous plant growth. Because all but a few exceptions retain their leaves (needles) throughout the year, they are ready to begin photosynthesis as soon as temperatures permit without having to produce a new set of leaves to do the work.

Thus, we find a great band of coniferous forests (the **boreal forests**, or **taiga**) dominated by spruce and fir species, with pines on sandy soils, sweeping the full breadth of North America and Eurasia northward of the 50th parallel of latitude, approximately occupying the region of Köppen's subarctic climate (see again Fig. 8.6). Conifers differ from other trees in that their seeds are not enclosed in a case or fruit but are carried naked on cones. All are needle leaf and drought resistant, but a few are not evergreen. Thus, a large portion of eastern Siberia is dominated by larch, which produces a mix of deciduous, coniferous forest. In this area,
January mean temperatures may be −35°C to −51°C (−30°F to −60°F). This is the most severe winter climate in which trees can maintain themselves, and even needle-leaf foliage must be shed for the vegetation to survive. Hardy broad-leaf deciduous birch trees share this extreme climate with the indomitable larches.

Extensive coniferous forests are not confined to high-latitude areas of short summers. Higher elevations in middle-latitude mountains of the Northern Hemisphere have forests of pine, hemlock, and fir (Fig. 11.28), with subalpine larch and specially adapted pine species characterizing the harshest and highest forest sites. The forests along the sandy coastal plain of the eastern United States are there in part because of the sandy soils, but they may also reflect a stage in plant succession that in time will lead to domination by broad-leaf types. Similarly, a temporary stage in the postglacial vegetation succession of the Great Lakes area included magnificent forests of white pine and hemlock that were completely logged off during the late 19th century.

A more maritime coniferous forest occupies the West Coast of North America extending from southern Alaska to central California. It is made up of sequoias, Douglas fir, cedar, hemlock, and, farther north, Sitka spruce. Many of the California sequoias are thousands of years old and more than 100 meters (330 ft) high. The southern regions experience summer drought, and farther north, sandy, acidic, or coarse-textured soils dominate.

Grassland Biomes

Grasses, like conifers, appear in a variety of settings and are part of many diverse plant communities. They are in fact an initial form in most plant successions. However, there are enormous, continuous expanses of grasslands on Earth. In general, it is thought that grasses are dominant only where trees and shrubs cannot maintain themselves because of either excessive or deficient moisture in the soil. On the global scale, grassland biomes are located in continental interiors where most, if not all, of the precipitation falls in the summer. Two great geographic realms of grasslands are generally recognized: the tropical and the middle-latitude grasslands. However, it is difficult to define grasslands of either type using any specific climatic parameter, and geographers suspect that human interference with the natural vegetation has caused expansion of grasslands into forests in both the tropical and middle latitudes.

Tropical Savanna Grasslands

The tropical grassland biome differs from grassland biomes of the middle latitudes in that it ordinarily includes a scattering of trees; this is implied in the term savanna (Fig. 11.29). In fact, the demarcation between tropical scrub forest and savanna is seldom...
a clear one. The savanna grasses tend to be tall and coarse with bare ground visible between the individual tufts. The related tree species generally are low-growing and wide-crowned forms, having both drought- and fire-resisting qualities, indicating that fires frequently sweep the savannas during the drought season. Savannas occur under a variety of temperature and rainfall conditions, but generally fall within the limits of Köppen’s tropical savanna type. They commonly occur on red-colored soils, leached of all but iron and aluminum oxides, which become brackish when dried. They likewise coincide with areas in which the level of the water table (the zone below which all soil and rock pore space is saturated by water) fluctuates dramatically. The up-and-down movement of the water table may in itself inhibit forest development, and it is no doubt a factor in the peculiar chemical nature of savanna soils. Large migratory herds of grazing animals and associated predators, responding to the periodically abundant grasses followed by seasonal drought, characterized the savanna prior to widespread human disruption.

Middle-Latitude Grasslands

The middle-latitude grasslands occupy the zone of transition between the middle-latitude deserts and forests. On their dry margins, they pass gradually into deserts in Eurasia and are cut off westward by mountains in North America. However, on their humid side, they terminate rather abruptly against the forest margin, again raising questions as to whether their limits are natural or have been created by human activities, particularly the intentional use of fire to drive game animals. The middle-latitude grasslands of North America, like the African savannas, formerly supported enormous herds of grazing animals—in this case, antelope and bison, which were the principal means of support of the American Plains Indians.

Like the savannas, the middle-latitude grasslands were diverse in appearance. They, too, consisted of varying associations of plant species that were never uniform in composition. In North America, the grasses were as much as 3 meters (10 ft) tall in the more humid sections, as in Iowa, Indiana, and Illinois, but only 15 centimeters (6 in.) high on the dry margins from New Mexico to western Canada. Thus, the middle-latitude grassland biomes are usually divided into tall-grass and short-grass prairie, often with a zone of mixture recognized between them. Unlike growth in the tropical savannas, the germination and growth of middle-latitude grasses are attuned to the melting of winter snows, followed by summer rainfall. Whether the grasses are annuals that complete their life cycle in one growing season or perennials that grow from year to year, the factor that seems to account best for the tall-grass prairie—precipitation that is both moderate and variable in amount from year to year—is the principal hazard in the use of these regions as farmland. However, this hazard becomes much greater in the areas of short-grass prairie.

Tall-Grass Prairie

The tall-grass prairies (Fig. 11.30a) were an impressive sight; in some better-watered areas, they made up endless seas of grass moving in the breeze, reaching higher than a horse’s back. Flowering plants were conspicuous, adding to the effect. Unfortunately, this tall-grass prairie scene, which inspired much vivid description by those first encountering it, is barely visible anywhere today. The tall-grass prairies, which once reached continuously from Alberta to Texas, have been almost completely destroyed. Compared to their once vast extent, today only a few tall-grass prairie areas remain in government-protected preserves. Their tough sod, formed by the dense grass root network, defeated the first wooden plows, which had served well enough in breaking up the forest soils. But the steel plow, invented in the 1830s, subdued the sod and was aided by the introduction of subsurface tile for draining the nearly flat uplands and by the simultaneous appearance of well-digging machinery and barbed wire. These four innovations transformed the tall-grass prairie from grazing land to cropland.

In North America, the tall-grass prairie pushed as far eastward as Lake Michigan. Why trees did not invade the prairie in this relatively humid area remains an unanswered question. Further west, shallow-rooted grass cover is fully understandable because the lower soil levels, to which tree roots must penetrate for adequate support and sustenance, are bone dry. In such areas, trees can survive only along streams or where depressions collect water.

In Eurasia, tall-grass prairies were found on a large scale in a discontinuous belt from Hungary, through Ukraine, Russia, and central Asia, to northern China. The grasslands are known in South America as the pampas of Uruguay and Argentina, and in South Africa as the Veldt. Today, all of these areas have been changed by agriculture. The factor that seems to account best for the tall-grass prairie—precipitation that is both moderate and variable in amount from year to year—is the principal hazard in the use of these regions as farmland. However, this hazard becomes much greater in the areas of short-grass prairie.

Short-Grass Prairie

West of the 100th meridian in the United States and extending across Eurasia from the Black Sea to northern China, roughly coinciding with the areas of Köppen’s middle-latitude steppe climate, are vast, nearly level grasslands composed of a mixture of tall and short grass, with short grass becoming dominant in the direction of lower annual precipitation totals (Fig. 11.30b), and tall-grass prairie in semiarid regions that have higher annual precipitation (compare to Fig. 11.30a). On the Great Plains between the Rocky Mountains and the tall-grass prairies, the short-grass prairie zone more or less coincides with the zone in which moisture rarely penetrates more than 60 centimeters (2 ft) into the soil, so the subsoil is permanently dry. Moving toward the drier areas, the grassland vegetation association dwindles in diversity and, more conspicuously, in height to less than 30 centimeters (1 ft). This is a consequence of reduction in numbers of tall-growing species and greater abundance of shallow-rooted and lower-growing types. The total amount of ground cover also declines toward the drier margins as the deeply rooted, sod-forming grasses of the prairie grassland give way to bunchgrass species (so called because, instead of forming a con-
In their natural conditions, the short-grass prairies of North America and Eurasia supported higher densities of grazing animals—bison and antelope in the former, wild horses in the latter—than did the tall-grass prairies. Indeed, it is suspected that the specific plant association of the short-grass regions may have been a consequence of overgrazing under natural conditions. The short-grass prairies cannot be cultivated without the use of irrigation or dry farming methods; so they remain primarily the domain of wide-ranging grazing animals; however, today's animals are domesticated cattle, not the thundering self-sufficient herds of wild species that formerly made these plains one of Earth's marvels.

Eventually, lack of precipitation can become too severe even for the hardy grasses. Where evapotranspiration demands greatly exceed available moisture throughout the year, as in Köppen's desert climates, either special forms of plant life have evolved or the surface is bare. Plants that actively combat low precipitation are equipped to probe deeply or widely for moisture, to reduce moisture losses to the minimum, or to store moisture when it is available. Other plants evade drought by merely lying dormant, perhaps for years, until enough moisture is available to ensure successful growth and reproduction. The desert biome is recognized by the presence of plants that are either drought resisting or drought evading (Fig. 11.31). In extremely dry deserts, only a few plants can survive, and ground cover is much less common. In the driest parts of the Atacama Desert of Chile it is so arid that there is no vegetation at all in some locations (Fig. 11.32).

Plants that have evolved mechanisms to combat drought are known as xerophytes. They are perennial shrubs whose root systems below ground are much more extensive than their visible parts or that have evolved tiny leaves with a waxy covering to combat transpiration. They may have leaves that are needle-like or trunks and limbs that photosynthesize like leaves or that have expandable tissues or accordion-like stems to store water when it is plentiful (the succulent cacti). They may be plants that can tolerate excessively saline water or shrubs that shed their leaves until sufficient moisture is available for new leaf growth. The nonxerophytic vegetation consists mainly of short-lived annuals that germinate and hurry through their complete life cycle of growth—leaf production, flowering, and seed dispersal—in a matter of weeks when triggered by moisture availability. Like other species, these ephemeral plants also require days of a
certain length, so they appear only in particular months; therefore, the month-to-month and year-to-year variation in form and appearance of desert vegetation is enormous. Animals of the deserts are primarily nocturnal to avoid the searing heat of the daytime, and many have evolved long ears, noses, legs, and tails that allow for greater blood circulation and cooling. The similar life-forms and habits of the different plant and animal species found in the deserts of widely separated continents are a remarkable display of repeated evolution to ensure survival in similar climatic settings.

**FIGURE 11.31**
A host of drought-resistant plants can be seen across parts of Arizona. What drought-resistant adaptations can be easily observed?

**FIGURE 11.32**
The absence of vegetation shown here in the Atacama Desert in Chile is a clear indication of the extremely low rainfall and high evaporation rates experienced in this region. The Atacama Desert is the driest region in the world. Are there any reasons why humans might be found in such desolate regions?
Arctic and Alpine Tundra

Proceeding upward in elevation and poleward in latitude, we finally come to regions in which the growing season is too brief to permit tree growth. Nearing the poles, we enter a vast realm dominated by subfreezing temperatures and thin snow cover much of the year, so the ground is frozen to depths of hundreds of meters. Only the top 36–60 centimeters (15–25 in.) thaw during the short summer interval. Still, vegetation survives here and in fact forms a nearly complete cover over the surface. Such vegetation must be equipped to tolerate frozen subsoil (permafrost), icy winds, low sun angles, summer frosts, and soil that is waterlogged during the short growing season. The result is **tundra**—a mixture of grasses, flowering herbs, sedges, mosses, lichens, and occasional low-growing shrubs. Most of the plants are perennials that produce buds close to or beneath the soil surface, protected from the wind. Many of the plants show xerophytic adaptation—such as small, hard leaves—in response to extreme physiologic drought resulting from wind stress. This is particularly true in areas of alpine tundra where extended periods of waterlogging of soils are uncommon. The effect of wind is evident from the fact that the less exposed valleys within the tundra region are often occupied by coniferous woodlands.

In a band of varying width reaching across northern Alaska, Canada, Scandinavia, and northern Russia, several types of tundra are recognized: **bush tundra**, consisting of dwarf willow, birch, and alder, which grow along the edge of the coniferous forest; **grass tundra**, which is hummocky and water soaked during the summer (●Fig. 11.33); and **desert tundra**, in which expanses of bare rocks may be covered by colorful lichens. In a few ice-free valleys of Antarctica, only desert tundra occurs.

Alpine conditions are not exactly like those in the Arctic latitudes. The deeper snow cover of the high mountains prevents the development of permafrost, and the summer sun results in considerably more evaporation. However, many high areas are swept clean of snow by wind and are thus extremely exposed, supporting only desert tundra. Microclimate becomes an important control of vegetation because of the varying exposures to sun and wind. Nevertheless, the short growing season and severe wind stress produce an overall plant community similar to that in the Arctic regions (●Fig. 11.34).

Animals of the tundra obviously must cope with long periods of extreme cold as well as darkness. Many animals hibernate through the long Arctic winters (or the cold and windy alpine winters); others, such as the caribou of Alaska and Canada, migrate into the boreal forest to escape the extreme cold exacerbated by Arctic winds. Year-round residents, such as the polar bear and musk ox, must have extremely large fat reserves around their
large chests, in addition to extremely efficient fur. Many insects, such as the ubiquitous mosquito, cope with the extreme climate by emerging from eggs in the spring, maturing and laying eggs, and dying within one short Arctic summer. Enough eggs survive, buried under insulating snow, to continue the cycle in the following year.

Marine Ecosystems

The living organisms of the ocean can be divided into three groups according to where or how they live in the ocean. The first group is called **plankton**. Plankton is made up mostly of the ocean’s smallest—usually microscopic—plants (**phytoplankton**) and animals (**zooplankton**). These tiny plants and animals float freely with the movements of ocean water, are true “drifters,” and form the basis of the oceanic food chain. The second group is composed of the animals that swim in the water. This group, called **nekton**, includes fish, squid, marine reptiles, and marine mammals such as whales and seals (Fig. 11.35). The third group is composed of the plants and animals that live on the ocean floor. This group is called the **benthos**. It includes corals, sponges, and many algae; such burrowing or crawling animals as the barnacle, crab, lobster, and oyster; and attached plants such as turtle grass and kelp.

Life in the ocean depends on the sun’s energy and on the nutrients available in the water. Phytoplankton are the most important link in the ocean food chain. At the base of the marine food web, phytoplankton take the dissolved nutrients in the water and, through the process of photosynthesis, produce oxygen and foods needed by zooplankton and by the smallest nekton. Phytoplankton are the only food source for these animals, which in turn form the food source for larger carnivorous fish and marine mammals. These in turn are prey for still larger animals. For example, tiny shrimplike creatures known as krill are nicknamed the “power food of the Antarctic.” These crustaceans feed on plankton and then become the main food source for birds, penguins, seals, and whales.

The marine food chain just described is part of a full food cycle in the ocean because, through the excretions of animals and the decomposition of both plants and animals in the ocean, chemical nutrients are returned to the water and are again made available for transformation by phytoplankton into usable foods.

Phytoplankton also play an essential role in the production of oxygen for Earth’s atmosphere. In fact, the greatest concern of scientists who study the annual Antarctic “ozone hole” (see Chapter 4) is that excessive ultraviolet radiation will destroy or diminish the phytoplankton in the Antarctic and other oceans.

The uneven distribution of nutrients in the oceans and the fact that sunlight can penetrate only to a depth of about 120 meters (400 ft), depending on the clarity of the water, means that the distribution of marine organisms is also variable. Most organisms are concentrated in the upper layers of the ocean where the most solar energy is available. In deep waters, where the ocean floor lies below the level to which sunlight penetrates, the benthos organisms depend on whatever nutrients and plant and animal detritus filter down to them. For this reason, benthos animals are scarce in deep and dark ocean waters. They are most common in shallow waters near coasts, such as coral reefs and tide pools, where there is sunlight and a rich supply of nutrients and where phytoplankton and zooplankton are abundant as well.

The waters of the continental shelf have the highest concentration of marine life. The supply of chemical nutrients is greater in waters near the continents where nutrients are washed into the sea from rivers. Marine organisms are also concentrated where deeper waters rise (upwelling) to the surface layers where sunlight is available. Such vertical exchanges are sometimes the result of variations in salinity or density. A similar situation occurs where convection causes bottom layers of water to rise and mix with top layers, as is the case in cold polar waters and in middle-latitude waters during the colder winter months. Marine life is also abundant in areas where there is a mixing of cold and warm ocean currents, as there is off the northeastern coast of the United States (Fig. 11.36).

During the 1977 dives of the manned submersible vessel *Alvin* off the East Pacific Rise, scientists for the first time observed abundant sea life on the floor of the ocean at depths of more than 2500 meters (8100 ft). It was previously presumed that these cold (2°C/36°F), dark waters were a virtual biological desert. However, the undersea volcanic mountain range produces vents of warm, mineral-rich waters, which nourish bacteria and large colonies of crabs, clams, mussels, and giant 3-meter (10-ft) red tube worms. The discovery of this deep-ocean ecosystem, which exists without the benefit of sunlight, has caused scientists to rethink old theories about the ocean and its chemistry. This unusual “chemosynthetic” vent community has been observed more recently at several other oceanic ridge sites in the Pacific and Atlantic Oceans.