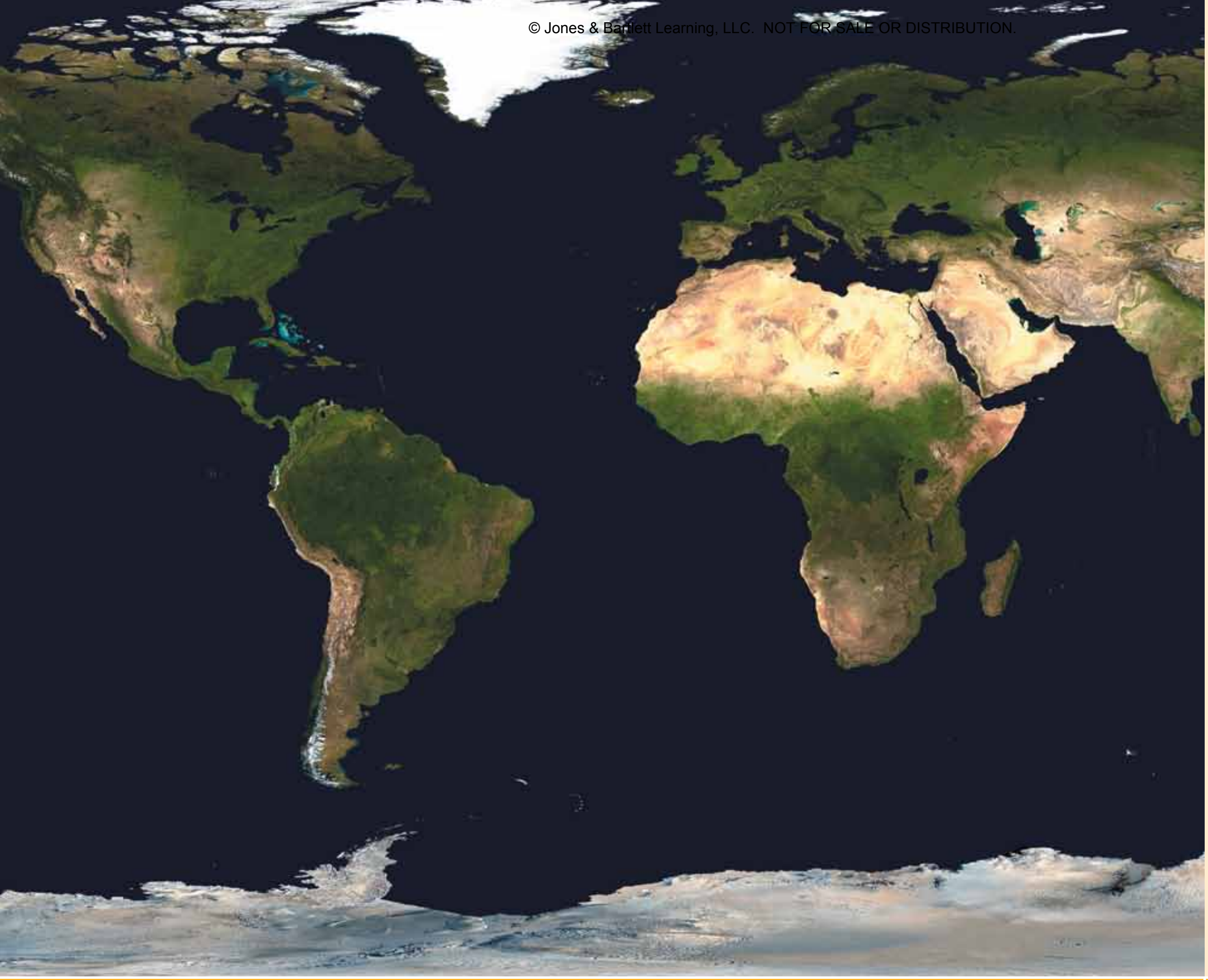

Life has co-evolved with the Earth's atmosphere, hydrosphere, and lithosphere to create an integrated "living" planet. Living things help cycle the elements and sustain an oxygen atmosphere while the Earth provides a habitable environment for life.

The Distribution of Life on Earth

4

This is a special time in Earth's long history. The continents are widely separated. The global climate is relatively cool compared with what it has been for most of Earth's history, and life has had time to adapt to its physical environment without interruption from a cataclysmic event. The Earth holds an unusually high number of species.

In this chapter, we examine how species originated and discuss estimates of the number of species on Earth today. We see that life arose rather early in Earth's history and has diversified into many species through the process of evolution via natural selection. Indeed, there are now so many species that biologists have scarcely begun the task of classifying and describing them all. Sadly, as species continue to disappear as a result of direct and indirect human activities, some species clearly will be gone before they are found and described. No one really knows how fast species are disappearing, but scientists put the numbers between 1,000 and 10,000 times what the normal or "natural" rate would be if people were not affecting the planet. A lack of professional biologists who are trained to study insects and other groups that are so abundant hinders the efforts to find and describe them. The information biologists can provide is very important in debates over how fast species are going extinct and what percentage of Earth's species are disappearing.

Chapter Objectives

After reading this chapter, you should be able to explain or describe the following:

- How life may have originated
- How life evolved and diversified by natural selection
- How to measure biodiversity
- The seven major land biomes of the world
- The two major aquatic biomes of the world

We also see how species are distributed on Earth. Species are neither randomly nor evenly distributed because their distribution is closely related to the physical conditions to which they are adapted. Rainfall and temperature are especially crucial in determining which suites of species can survive in any given region. Some species are narrowly adapted to very limited conditions in one area, whereas other species, such as the wolf, were once found across many continents. Human impacts, such as on species distributions, are not randomly or evenly distributed. Some regions, such as deserts, are more sensitive than others to our disturbance.

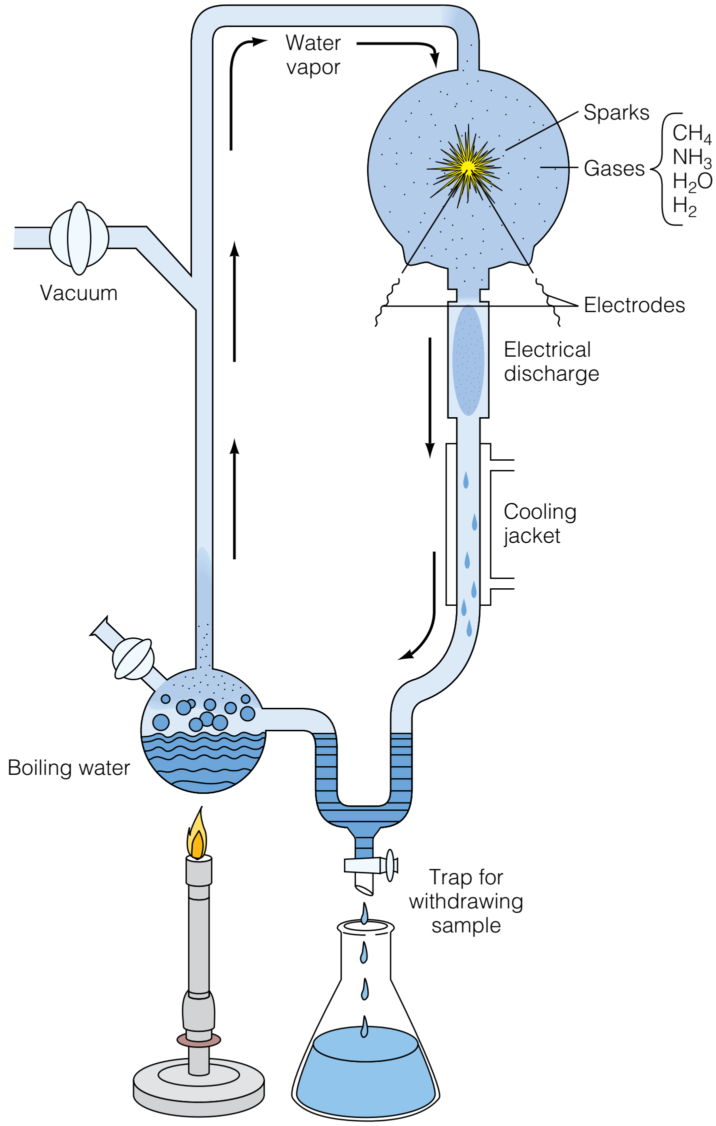

FIGURE 4-1 This is a simplified schematic of the experimental apparatus that Miller and Urey used to show that organic molecules can be produced from the chemical components of the Earth's early atmosphere.

Other regions, such as grasslands, with rich soils for crops, are affected because they are resource rich and we can rapidly exploit them.

4.1 Evolution of the Biosphere

Primitive fossilized bacteria are at least 3.5 billion years old. This indicates that life arose not long after the molten Earth first became cool enough to support life. This very early appearance of life implies that natural processes readily produce life under appropriate conditions. Beginning in the early 1950s with the work of Stanley Miller and Harold Urey, scientists have shown that the complex molecules possessed by all living things are readily produced under laboratory conditions that duplicate early environments on Earth. As **FIGURE 4-1** shows, the early atmosphere is thought to have been composed of ammonia (NH_3), methane (CH_4), water vapor (H_2O), and other gases. When these are subjected to electricity, which simulates lightning and sunlight, chemical reactions occur that produce **amino acids**. Amino acids are complex molecules that are the building blocks of proteins. Proteins make up enzymes and many other components of life, such as muscles, hair, and skin.

Of course, protein molecules alone are not living things. Organisms are composed of molecules that are organized in very complex ways. The basic organizational unit of life is the cell. Remarkably, in the late 1950s, Sidney Fox found that heated amino acids can form cell-like structures sometimes called **protocells**. These structures are not true cells but have many cell-like properties, such as being semipermeable to certain materials.

Producing amino acids and protocells in the laboratory is far from creating life in the laboratory. Even the simplest bacteria are considerably more complex than these protein and protocellular building blocks. Nevertheless, the readiness with which these first steps toward life occur, combined with the fossil record, support the idea that life readily arose through natural processes.

Evolution Through Natural Selection

After life originated, it began to diversify into different kinds of organisms through biological evolution. As Charles Darwin documented in 1859, biological evolution occurs because of **natural selection** of individual variation:

1. Nearly all populations exhibit variation among individuals.
2. Individuals with advantageous traits will tend to have more fertile offspring.
3. Advantageous traits will therefore become widespread in populations.

Variation in neck length in giraffes is an example. We know from fossils that early giraffes had relatively short necks. However, a few individuals had genes that produced slightly longer necks. In some localities, these giraffes had a feeding advantage because they could browse on leaves in taller trees. Consequently, in populations living where tall trees were common, longer-necked giraffes tended to have more offspring and passed on genes for longer neck growth so that longer necks became more common.

If this process occurs with many traits over a long period of time, the population will eventually become very different from other populations and will create a new species. **FIGURE 4-2** illustrates how isolation of populations promotes speciation. The different populations are exposed to different environments, which favor different traits, causing the populations to diverge through time. When do two different populations become two different species? Biologists generally define a **species** as a group of individuals that can interbreed to produce fertile offspring (this definition applies only to sexual organisms; the issue of defining nonsexual species is a matter of debate in biological circles). Therefore, a new species is formed when members of a diverging population can no longer successfully mate with populations of the ancestral species. Closely related species, which have often diverged relatively recently, are grouped together within the same genus. Similar genera are then grouped together within the same family. This method of classifying species according to hierarchically nested categories is a form of **taxonomy**. Applying this system to humans, we have the following:

Kingdom Animalia
Phylum Chordata
Class Mammalia
Order Primates
Family Hominidae
Genus *Homo*
Species *H. sapiens**

Diversification of the Biosphere

Where does individual variation come from? This question is crucial because without the initial variation in the population, natural selection would have nothing to act on. This question troubled Darwin because he was not aware of the work of Gregor Mendel, who is credited with discovering the laws of inherited variation in 1865. Indeed, initially Mendel's work was overlooked, and scientists rediscovered it only in the early 1900s. Mendel discovered that **genes**, which are the basic units of heredity, pass on traits. According to the Human Genome Project, humans have an estimated 30,000 to 40,000 genes that determine our traits. Variation in a population, or gene pool, occurs because individuals possess different sets of genes that produce different traits. How do different sets of genes arise? Reproduction is one way. Genes are shuffled when sperm and egg cells are fused, causing offspring from the same parents to have different genes. A second cause of genetic variation is **mutation**, which is a spontaneous change in a gene. Genes are composed of **DNA** molecules, and mutations occur when DNA molecules are altered, such as during DNA replication. Mutation is the ultimate source of all genetic variation.

Patterns of Diversification

Evolution through natural selection has produced an increasingly diverse biosphere, with the total number of species becoming greater through time. Initially, evolution was relatively slow. The right side of **FIGURE 4-3** summarizes the evolution of life on Earth. For about 2 billion years after the first appearance of fossils, relatively few species of simple single-celled organisms, such as various bacteria and Cyanobacteria (formerly

*A species name must always be associated with a generic name or abbreviation (in this case *H.* for *Homo*). Humans are the species *Homo sapiens*; it is incorrect to call humans simply *sapiens*.

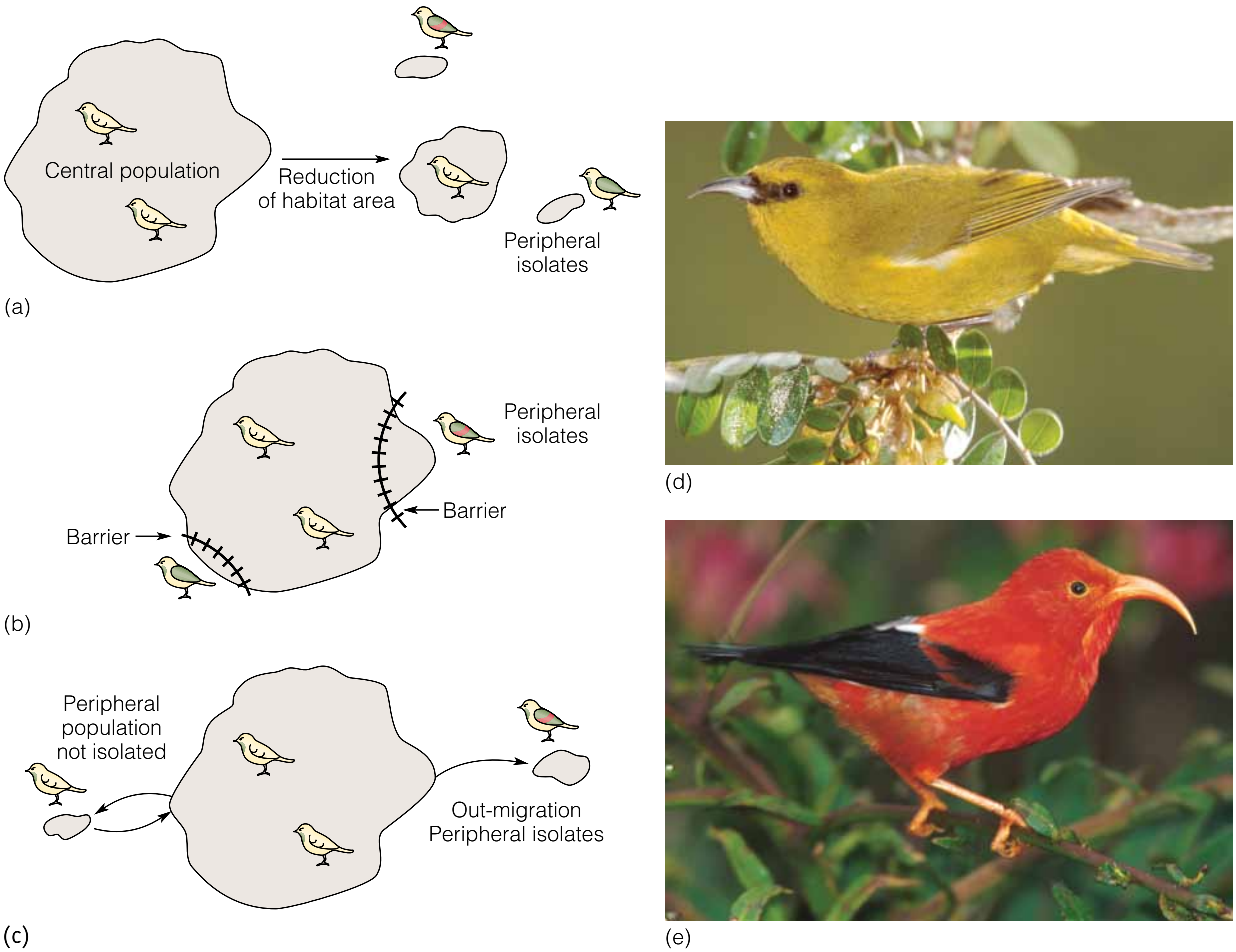

FIGURE 4-2 (a) Reduction of habitat may leave small isolated populations, called peripheral isolates. (b) Barriers may form to isolate small populations. (c) Out-migration to an isolated area may form small separated populations. In all cases (a–c), the small populations can evolve into new species. Isolated by thousands of miles of ocean, the Hawaiian honeycreeper has evolved into many forms, including species with short (d) and long (e) beaks. © Jack Jeffrey Photography.

known as blue-green algae), appear in the fossil record. A major change occurred about 1.5 billion years ago when more complex cells, called **eukaryotes,** evolved. These cells had a true nucleus, chromosomes, and specialized cellular organelles such as mitochondria. Apparently, such complex cells were a primary impetus of increasing rates of evolution. Multicellular organisms, including sponge-like and jellyfish-like creatures, appeared in the oceans by at least 1 billion years ago. These probably evolved from colonies of single-celled eukaryotes, such as protozoa, that became progressively more specialized and integrated. About 570 million years ago, the fossil record shows a rapid diversification, sometimes called the **explosion of life** or the **Cambrian explosion,** when most of the major groups of animals first appear. As shown in Figure 4-3, this explosion (which occurred during the Cambrian Period of Earth history) corresponds to the time when modern oxygen levels were attained in the atmosphere. This permitted the evolution of more complex animals, which have a greater metabolic need for oxygen.

After the explosion of life, living things diversified into new environments. As shown in Figure 4-3, life colonized the land (lithosphere) and the air (atmosphere) during the Paleozoic Era, which began with the explosion of life and ended with a global mass extinction. The Mesozoic Era, sometimes called the age of dinosaurs, was the second major era, and it also ended with a mass extinction. The third and last era is the Cenozoic Era, sometimes called the age of mammals. Although catastrophes, especially from aster-

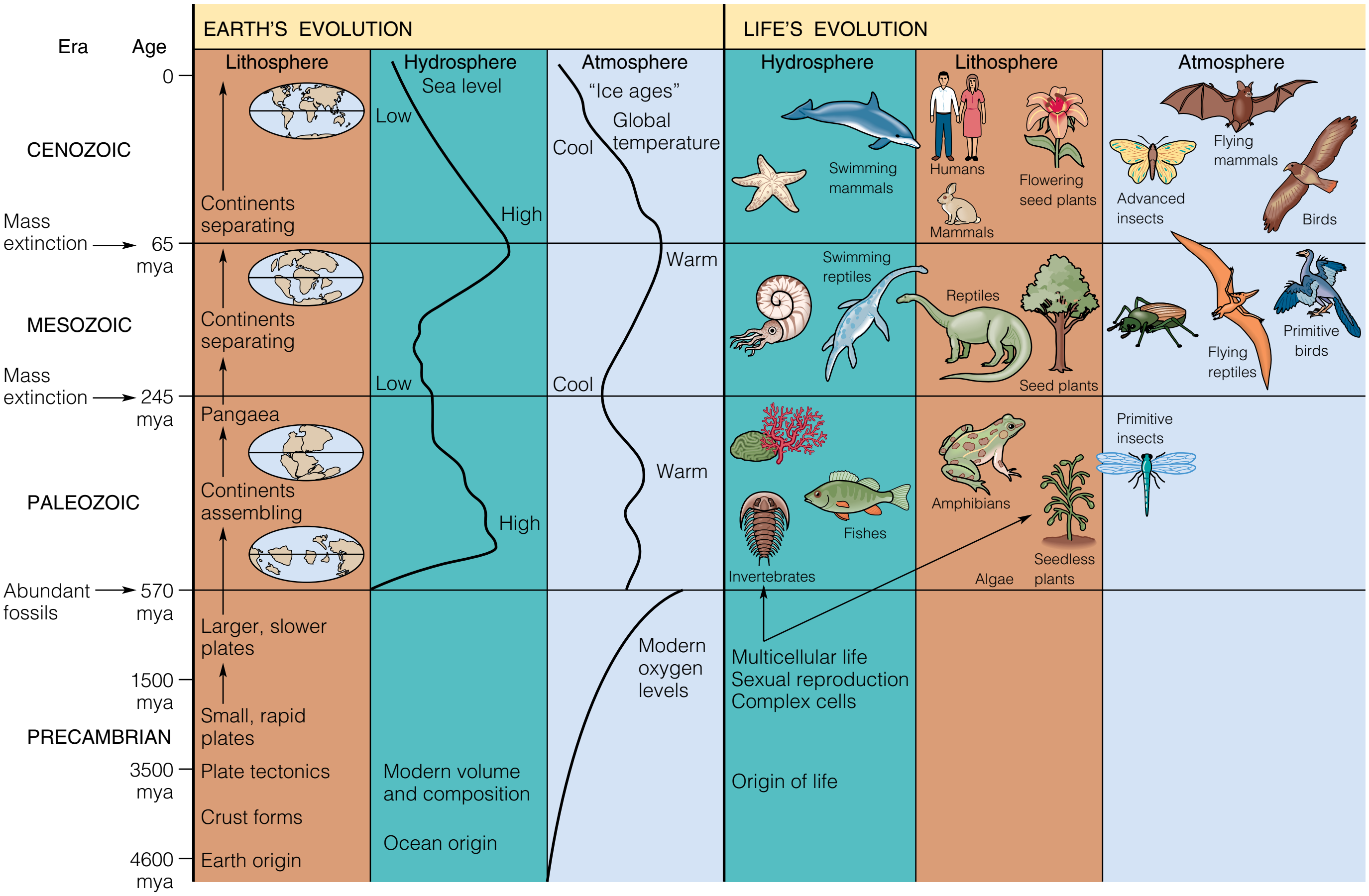

FIGURE 4-3 The left side of this diagram summarizes the changes in the Earth's continents, oceans, and atmosphere, whereas the right side summarizes the evolution of life on Earth.

oid and comet impacts and global climate change, have temporarily caused species numbers to decrease through mass extinctions at very rare intervals, the overall trend throughout these eras is toward increasing numbers of species. Life has adapted to new environments and found new ways of doing things through mutation and natural selection. We now live in a biosphere that is one of the most diverse in life's long history.

4.2 What Is Biodiversity?

Biological diversity, or **biodiversity**, has many definitions, but they all involve the variety of living things in a given area. For instance, the U.S. Office of Technology Assessment defines biodiversity as "the variety and variability among living organisms and the ecological complexes in which they occur." One reason for the lack of a precise definition is that life is hierarchical. For example, genes occur in cells. Cells occur in organisms, and organisms occur in ecosystems (a review of the biosphere provides more information). At what level do we measure the diversity of life in an area? The number of genes? Organisms? Ecosystems? All can be used.

Measuring Biodiversity

Although one can measure biodiversity by counting the variety of genes or ecosystems in an area, the most common method is to count species. *Species diversity* is usually measured as **species richness**, which is the number of species that occur in an area. Using species richness is largely a matter of convenience: it is easier to tabulate the number of species in an area than to count genes (the genetic diversity) or ecosystems. Fortunately, species diversity is generally a good indicator of genetic diversity and ecosystem diversity as well. Nevertheless, even species richness omits important information about biodiversity, such as the abundance of each species. Species evenness is the distribution of individuals among species in a community.

Biodiversity can be measured at all geographic scales, from local to regional to global. **FIGURE 4-4A** illustrates low diversity at both the local and regional scales. Regions with low diversity often have fewer species at the local level as well. As **FIGURE 4-4B** illustrates, regions with high diversity tend to be composed of local biological communities with high diversity. For instance, tropical rain forests and tropical coral reefs tend to have very high species richness at both the local and regional level compared with areas of similar size in temperate zones.

Global Biodiversity: How Many Species?

No one knows how many species live on Earth. **Taxonomists**, the biologists who classify and describe organisms, have described approximately 1.8 to 2.0 million species. Of these, 56% are insects, and 14% are plants; vertebrates such as birds, mammals, and fishes are just 3%. Only about 15% of described species occur in the oceans.

However, these 2 million species are a highly biased sample and may not reflect the true species richness of the biosphere. For one thing, vertebrates are much more widely studied and, therefore much better known than nonvertebrates: only one or two new species of birds are described each year, whereas hundreds of new invertebrates are found. A recent study reported more than 4,000 bacteria species in a single gram of Norwegian soil. Most of these species were previously unknown.

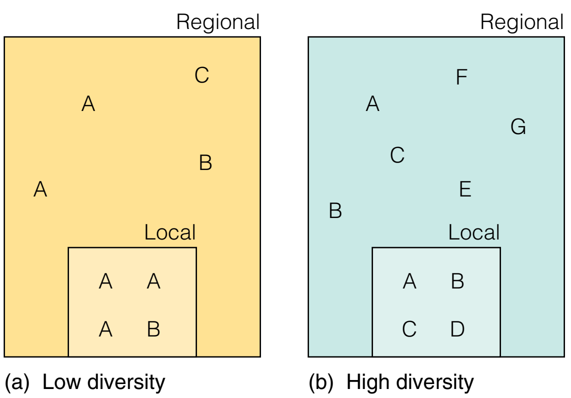

FIGURE 4-4 Letters (A, B, C, and so forth) represent species living in an area: (a) low diversity at both the local and regional scales; (b) high diversity at both scales.

Another problem is that most biologists have been concentrated in North America and Europe, but the tropics have the most species. Similarly, most biologists study life on land, but the oceans cover 70–75% of the Earth and contain unknown numbers of species. For instance, after a December 2004 tsunami that hit Southeast Asia, many rarely seen species were found washed up on the shores. It is likely that taxonomists have considerably underestimated the number of species existing in the tropics and the oceans.

How Estimates Are Made

Describing all species on Earth could take centuries, so biologists have devised a number of ways to develop immediate biodiversity estimates of species numbers from limited information. The following are just three examples of the many methods of estimating global diversity from small samples:

1. *Rain forest insect samples.* Terry Erwin of the Smithsonian Institution has become well known for his studies of the very diverse tropical insect communities. Because most species are insects and most insects are tropical, these studies are important for global estimates (**FIGURE 4-5**). Erwin used insecticides to kill and collect all of the insects in the canopy (upper branches) of a tropical tree. In Panama, for example, 1,200 beetle species were found in the canopy of a single tree. Because about 40% of all insects are beetles, we can estimate that perhaps 3,000 insect species occur there; however, only about two-thirds of the species occur in the canopy (the rest occur on roots, bark, and other places). The total number of insects on this one tree is thus estimated at 4,500 species! Because many of these insects occur only on one tree species and because there are about 50,000 species of tropical trees, it seems that many tropical insect species must exist. Erwin estimates the insect species on Earth at more than 30 million.

How Does Biodiversity Affect the Provisioning of Ecosystem Services?

CASE STUDY 4-1

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Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss in the diversity of life on earth. The first major finding of the Millennium Ecosystem Assessment (MA, 2005a) clearly links the rapid and widespread loss of biodiversity on Earth to the growing intensity of many human pressures on biodiversity. According to the MA's Biodiversity Synthesis (MA, 2005b), the most important direct drivers of biodiversity loss and ecosystem service changes are habitat change (such as land use changes or physical modification of rivers), climate change, invasive alien species, overexploitation, and pollution. Thus, biodiversity loss is linked to "the degradation of many ecosystem services [and] could grow significantly worse during the first half of this century [. . .]" (MA, 2005b).

The Millennium Ecosystem Assessment indicates that human activities over the last 50 years have affected ecosystems across the globe more quickly and profoundly than any other time. In fact, we are now in the midst of one of the major extinction events on Earth. The report states: "Appropriating major parts of the energy flow through the food web and altering the fabric of the land cover to favor the species of greatest value have increased the rate of species extinction 100 to 1,000 times the rate before human dominance on Earth." Current trends, such as population growth and climate change, affect ecosystems and the biodiversity that underpins these ecosystems negatively; yet, without major intervention, the threat to global biodiversity will worsen.

In addition to the moral reasons to preserve biodiversity for its own sake, biodiversity provides a plethora of ecosystem services that are critical to not only overall human well-being but also our very survival on earth. Biodiversity can affect ecosystem services both directly and indirectly. Directly, humans derive most of their essential food and fibers from animals and plants. More indirectly, biodiversity can affect the provision of ecosystem services through its influence on ecosystem processes that are essential to Earth's life support systems.

> "By affecting the magnitude, pace, and temporal continuity by which *energy* and materials are circulated through ecosystems, biodiversity influences the provision of regulating ecosystem services, such as *pollination* and seed dispersal of useful plants, regulation of climatic conditions suitable to humans and the animals and plants they consider important, the control of agricultural pests and diseases, and the regulation of human health. Also, by affecting nutrient and water cycling, and soil formation and fertility, biodiversity indirectly supports the production of food, fiber, potable water, shelter, and medicines." (Diaz, 2010).

Based on available evidence, it is difficult, if almost impossible, to conclude how many species are needed to preserve different ecosystem services. However, moral reasons and the precautionary principle suggest that in all ecosystems as many existing species as possible should be preserved. In general, because most ecosystem services are provided at the local scale, if we are to preserve the regulating and supporting services that ecosystems provide to humans, conservation efforts need to focus on preserving or restoring their biotic integrity (whether inherently species-poor or species-rich), rather than on simply maximizing the number of species present (Diaz, 2010).

Regarding the decrease of ecosystem services as a result of rapid biodiversity loss, not all communities will be similarly affected. In fact, it is more likely that people who rely most directly on ecosystem services, such as subsistence farmers and fishers, the rural poor, and traditional societies, face the most serious and immediate risks. In large part this results from these individuals and communities relying most directly on the benefits provided by the biodiversity of natural ecosystems in terms of food security, sustained access to medicinal goods, construction materials, and fuel. Furthermore, these communities and individuals are the most likely to suffer from storms and floods that may increase as a result of ecosystem degradation. Finally, less privileged socioeconomic sectors are also less able to substitute purchased

CASE STUDY 4-1 How Does Biodiversity Affect the Provisioning of Ecosystem Services?

goods and services and have less purchasing power and often less political power. Thus, the loss of biodiversity-dependent ecosystem services is likely to accentuate inequality and marginalization of the most vulnerable sectors of society.

However, during the past few decades, more people have become aware of the impact on biodiversity and the threats of those impacts on critical ecosystem services. Many countries have biodiversity protection programs of varying degrees of effectiveness, and several international treaties and agreements coordinate measures to slow or halt the loss of biodiversity. For example, the United Nations Environment Programme has played a major role in the establishment of major multilateral environmental agreements, including the Convention on Biodiversity. This convention came into force on December 29, 1993, during the 1992 earth summit in Rio de Janeiro. The United Nations declared 2010 as the International Year of Biodiversity to help draw attention to the importance of global biodiversity conservation efforts.

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Millennium Ecosystem Assessment (MA). 2005b. *Ecosystems and human well-being: Biodiversity synthesis*. World Resources Institute, Washington, DC.

Diaz S. 2010. Biodiversity and ecosystem services. Online at: http://www.eoearth.org/article/Bio-diversity_and_ecosystem_services?topic=49575

For more information on international efforts: http://www.unep.org/iyb/unepwork.asp

2. *Ecological ratios*. Another method is to use well-studied groups to predict the diversity of less studied groups that are associated with them. For example, in Europe, there are about six fungus species for each plant species. Plant species have been relatively well described, and it is estimated that 270,000 plant species exist worldwide. Thus, there may be as many as 1.6 million fungus species if the 6:1 ratio is applicable throughout the world. Only 69,000 fungus species have been described.
3. ***Species area curves***. The species area curve has been very influential since the 1960s. Whenever the number of species is counted in a gradually enlarged area of sampling, the result is a curve as in **FIGURE 4-6**. The number of species rises rapidly at first, but it slows as the area of sampling increases because the same species are encountered again and again. Repeated surveys in the tropics and temperate areas have shown that small areas of rain forest contain many more species, often more than 100 times more species, than comparable areas of temperature forest. By using the known shape of the species area curve, one can predict how many more species will be found in larger unsampled areas of tropical and temperate regions.

FIGURE 4-5 Each of the tropical trees in this expanse can be home to hundreds of insect species. © Photodisc.

2ND PAGES

CASE STUDY
4-2

Hellbenders and Alligators: The Asia-U.S. Connection

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The geographic distribution of species is partly dependent on their biological adaptations, such as how well a species can tolerate cold winters. However, in many cases, the history of a group also plays an important role in its current distribution. A good example of this is the presence of some plants and animals in eastern North America.

As early as 1750, the famous biologist Linnaeus noticed a curious similarity between many species in eastern North America and species in Eastern Asia. A century later, Charles Darwin discussed this relationship as well. For example, a giant salamander called the hellbender, found only in the southern Appalachian region, belongs to a salamander family with all of its other species in Asia (**FIGURE CS 4-1**). Similarly, there are only two species of alligators in the world: the American alligator, which is found throughout the southeastern United States, and the Chinese alligator. Primitive fishes also show this pattern. The paddlefish is an archaic fish with a long snout able to detect magnetic fields of its prey in murky waters. The only species of this family outside of the United States occurs in the Yangtze River system of China.

An even more striking relationship is seen among plants: the broadleaf deciduous forests of eastern Asia and eastern North America have a great resemblance to one another. Most notable are similarities among primitive flowering plants, descended from plant families that appeared more than 70 million years ago when dinosaurs were still alive. These include members of the magnolia family, which has many species in both eastern Asia and eastern North America. In some cases, the species themselves are very similar, such as the tulip poplar that occurs in both regions. Even some herbs have striking similarities. The medicinal herb ginseng has but two closely related species, with one occurring in eastern North America and the other in eastern Asia.

CS 4-1 FIGURE 1 Hellbender salamander. © Brad Moon.

What is the cause of this biological connection between Asia and eastern North America? Many people have suggested the North American plants and animals may have colonized North America in the same way as the American Indians. These early arrivals migrated across the Bering Sea land bridge from Asia through Alaska several thousand years ago; however, the very ancient geological age of nearly all of these groups suggest that they became separated much longer than a few thousand years ago. Paleobiologists have found that about 40 million years ago there was a land-bridge connection across the North Atlantic. It ranged across northern Asia through northern Europe into Greenland and northern Canada. The climate of the Earth was much warmer at this time, so it permitted the migration of species adapted to warm climates. By 30 million years ago, the Earth had cooled to the point where such migration was no longer possible. These groups have been isolated from Asia ever since.

This example illustrates how understanding the history of life helps us value its preservation. We see that many of the species that constitute the eastern North American forests are part of a very ancient ecosystem. These species belong to groups with a very long evolutionary heritage, and they contain very ancient genetic diversity.

Questions

1. Name three species that might be called "living fossils" because they have a very long evolutionary heritage.
2. Botanists have long noted that ornamental plants from eastern Asia are among the easiest plants for landscapers to cultivate in eastern North America. Why is this?

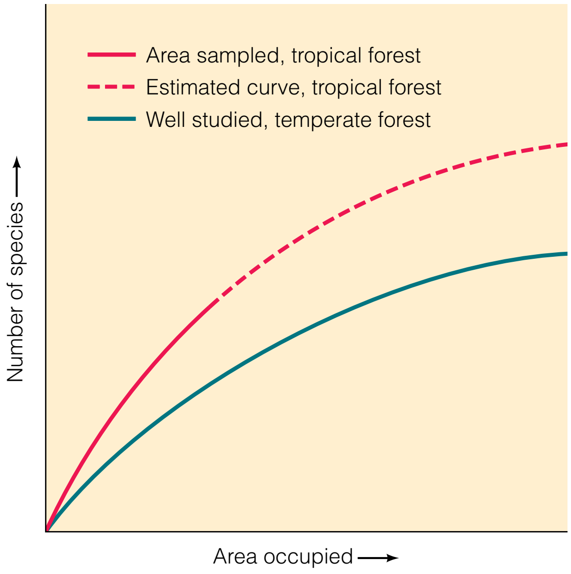

FIGURE 4-6 A species area curve plots the number of species found in increasingly larger areas. The temperate forests are well studied compared to tropical forests. Only small areas have been examined in most tropical forests so data are derived from extrapolated projections as indicated by the dashed line.

Biodiversity Today: A Rare Wealth in Time

All methods of estimating global biodiversity involve a certain amount of extrapolation; so understandably, there is still wide disagreement over how many species exist. Estimates range from as low as 3 million species to as high as 100 million or more. However, biologists generally agree that fewer species live in the ocean than on land. Estimates for the ocean range from 1 million to 10 million species. Despite having fewer species, however, the oceans have more fundamental biodiversity: 32 phyla are found in the oceans compared with just 12 phyla on land. A phylum, such as echinoderms or mollusks, is a much more distinct taxonomic unit of biodiversity than a species.

Whatever the exact number of species today, the fossil record indicates that we live during a special time of Earth's history. Detailed compilations of fossil data show that the number of families in the oceans has generally increased through time (**FIGURE 4-7**). Evolution has produced new families that have added to overall biodiversity. Estimates based on species produce similar results. We apparently live at a time when global biodiversity is near or at its all-time peak. As we discussed in our review of the biosphere, the individual organisms composing this diversity are organized into populations, and all of the populations of a certain geographic area form a community. In the remainder of this chapter, we briefly describe some of the broad types of natural communities that occur on Earth today.

4.3 Biomes and Communities

A **biome** is a large-scale category that includes many communities of a similar nature. Many thousands of communities exist on the Earth, but rather than describe each in detail, we examine the basic categories into which communities can be grouped.

The most basic distinction is between terrestrial (land)- and aquatic (water)-dwelling communities. There are seven major types of terrestrial biomes and two major types of aquatic biomes:

1. *Terrestrial.* Tundra, grassland, savanna, desert, taiga, temperate forest, tropical forest (including tropical rain forests)
2. *Aquatic.* Marine, freshwater

Both terrestrial and aquatic biomes (and thus the communities within them) are largely determined by climate, especially temperature. Climate is so important because it affects many aspects of the physical environment: rainfall, air and water temperature, soil conditions, and so forth. However, secondary factors such as local nutrient availability are also important. In all cases, biomes illustrate the key point that species often will adapt to physical conditions in similar ways, no matter what their evolutionary heritage. A desert biome in the western United States looks superficially similar to a desert biome in North Africa even though the plants have different ancestries.

Terrestrial Biomes

Of the seven basic land biome types commonly distinguished (tropical forests, savanna, grasslands, deserts, temperate forests, taiga, and tundra—each of these is described and illustrated), the tundra and desert biomes represent adaptations to the extreme conditions of very low temperature and low water, respectively. Not surprisingly, communities in these

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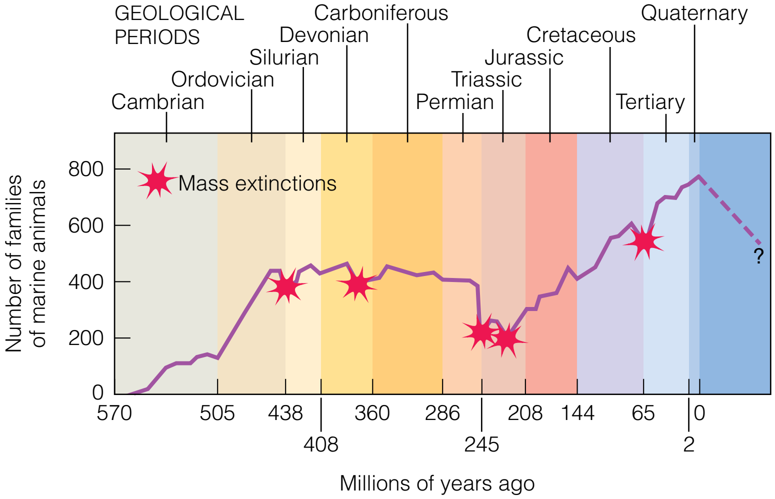


FIGURE 4-7 The number of families in the ocean has generally increased until the present. Five mass extinctions have temporarily lowered biodiversity. Will a sixth mass extinction occur in the near future? *Source:* Modified from D. Raup, J. Sepkoski. Mass extinctions in the marine fossil record. Science 1982;215:1501–1503.

biomes tend to have the least number of species because organisms have difficulty adapting to the extreme physical conditions. In contrast, the tropical rain forests tend to be richest in species, in part because the tropics have the most moderate overall conditions.

FIGURE 4-8 illustrates the approximate distribution of some of the major land biomes by precipitation, altitude, and latitude. This figure demonstrates the importance of temperature, which decreases with both increasing altitude, and increasing latitude; similar changes result in both cases. In addition, note the importance of precipitation, ranging from the very moist equatorial regions to the desert biome. A more detailed global view in **FIGURE 4-9** shows some of the true complexities of the latitudinal pattern. For example, tropical forests are not always neatly confined to equatorial areas.

We now describe seven major terrestrial biomes (listed in approximate order going from the equator to the poles).

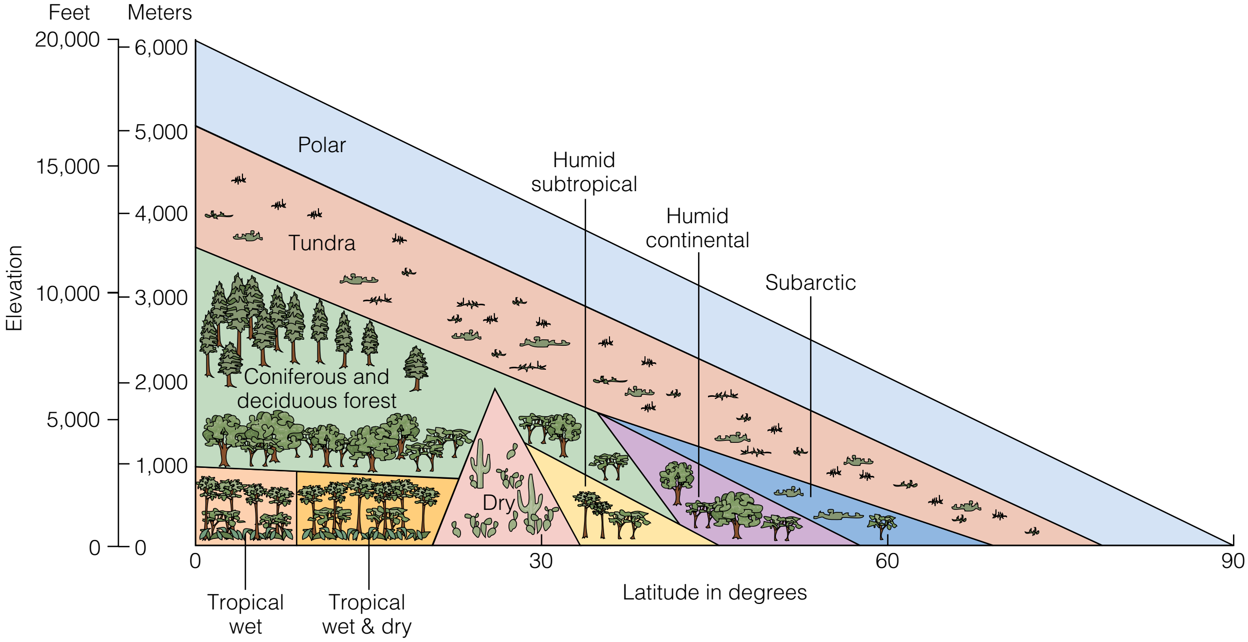


FIGURE 4-8 Vegetation changes with altitude in the same way as with latitude because both changes are associated with decreasing temperatures.

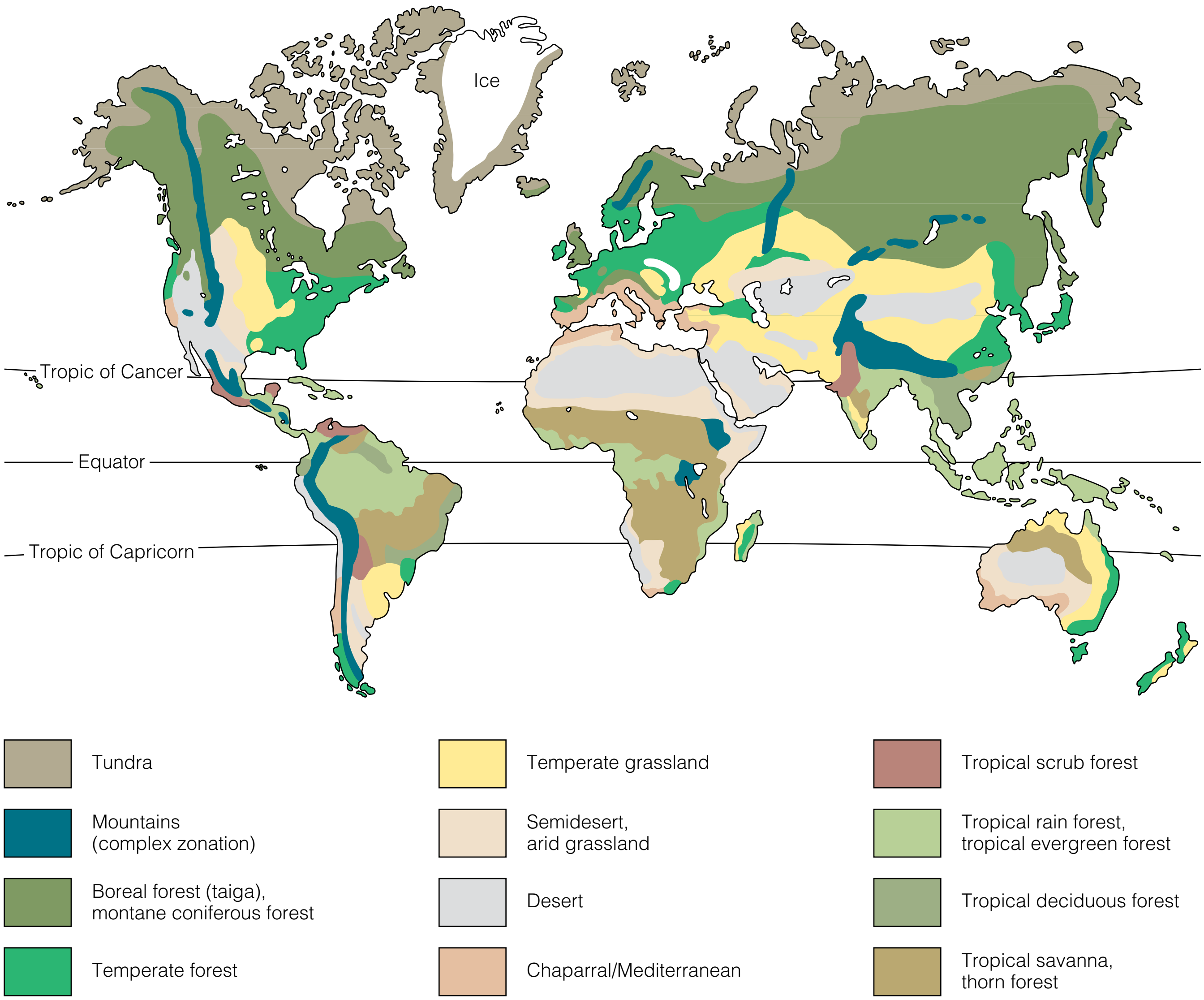


FIGURE 4-9 The major terrestrial biomes of the world.

Tropical Forests

Although rain forests are the best known kind of tropical forest, there are actually several types. Tropical seasonal forests occur in dry areas of the tropics, where pronounced dry periods cause the trees to be deciduous (drop their leaves). Tropical seasonal forests are common in parts of Southeast Asia, especially India, where they are often called "monsoon forests" because the rain-bearing monsoon winds carry the moisture that restarts forest growth after the dry season. In contrast, tropical rain forests are evergreen forests where plants show no major seasonal changes. Another type of tropical forest is the tropical woodland. This occurs in parts of the tropics where rainfall is relatively rare throughout the year, such as areas of Central America and central Africa. Because of the moisture limitations, photosynthesis and plant productivity are only about one-third that of the tropical rain forest.

Tropical forests are found on most major continents, mainly in equatorial regions (Figure 4-9). These represent the most complex and diverse biome, containing perhaps more than 50% of the world's species while occupying only 7% of the land area. Unfortunately, people have deforested approximately half of this area; and consequently, many rain forest species are on the brink of extinction. The high biodiversity of tropical rain forests is partly due to the relatively constant temperatures and high water availability: daily and seasonal changes (fluctuations) are usually less than a total of 5°C (9°F). Rainfall is very heavy, ranging from 200 to 450 centimeters per year (80 to 175 inches). In comparison, Seattle, Washington, receives an average of 100 centimeters (37 inches) of precipitation annually. The average temperature of the tropical rain forest biome is about 25°C (77°F to 80°F). In comparison, New Orleans, Louisiana, has an average temperature of just 20°C (68°F).

This lack of pronounced seasonal temperatures, including longer days and more direct sunlight, provides more opportunity for plant growth and productivity in this biome. The result is an ecosystem of very high species diversity and structural complexity (**FIGURE 4-10**). This structural complexity is seen in the many layers of trees forming a multistoried canopy. The canopy blocks out most of the sunlight so that, in contrast to popular conception, the forest floor is relatively dark and does not support dense vegetation. Plants living at ground level must have special adaptations for coping with the lack of sunlight. For example, many plants have very broad leaves (such as the common "elephant ear" plant) to maximize surface area and very dark green pigmentation (chlorophyll) to maximize light absorption. Another common adaptation is found among epiphytes (plants that grow on the branches of trees) and vines, which grow up tree trunks to capture light in gaps high in the canopy.

FIGURE 4-10 The complex (multilayered) structure of a tropical rain forest. © Photodisc.

The high species diversity of tropical rain forests has also led to the misconception that they must have very fertile soils. In fact, the soils here are quite poor (low in phosphorus, nitrogen, and other nutrients) because they are depleted by the intense competition among the abundant fast-growing plants for nutrients. The hot, humid climate makes tropical rain forests an ideal environment for bacteria, fungi, termites, and other soil organisms, which quickly decompose matter on the forest floor. Most of the free nutrients remaining in the soil are leached away by the high rainfall. The result is that nearly all nutrients are tied up in the biomass of the plants and animals living in the rain forest. The only way to release these nutrients for farming is to cut and burn the vegetation by "slash-and-burn" agriculture. Unlike the temperate forest biome (discussed later), tropical forests on different continents vary widely in the genera and families of plants that compose them. This is probably a result of the relative isolation and rapid evolution of species in tropical ecosystems. In addition, most tropical forest plants (especially trees) belong to botanical families that are rarely, if ever, found in temperate latitudes. This gives the rain forest its exotic appearance to visitors from North America and other temperate latitudes.

In most ecosystems, there is a strong correlation between the diversity of plant species and the diversity of animal species; so it is not surprising that the diverse tropical plant life supports a proportionately rich diversity of animal life. It has been estimated, for example, that more than 90% of earth's insect species are found in the rain forests. This high diversity is true for many other animal groups, such as mammals and especially birds, which are much more diverse in the tropics than other biomes (**FIGURE 4-11**).

FIGURE 4-11 Macaws range from southern Mexico down into central South America. This is a blue and gold macaw. © Photodisc.

Savannas

Savannas occur in tropical and subtropical areas that are not wet enough to support rain forests. Probably the best known of these are the savannas of Africa and South America, but they also occur in tropical regions of Australia and Asia (Figure 4-9). These regions are warm and have prolonged dry seasons with annual rainfall averaging 90 to 150 cm (35 to 60 inches). Such climatic conditions support vegetation of open grasslands with scattered shrubs and trees (see **FIGURE 4-12**). The grasses grow rapidly during the rainy season and dry up during the dry season while the few trees survive by growing deep root systems to access groundwater supplies. In areas of increasing rainfall, woodland begins to replace the savanna as tree density increases. Some savanna-like environments with dense scrubby evergreen vegetation are called **chaparral**. Examples occur in California and the Mediterranean region (Figure 4-9).

FIGURE 4-12 Savanna in Kenya. © Photodisc.

Many people are familiar with the big-game animals of the African savanna, including such large herbivores as wildebeests, zebra, rhinoceroses, and buffalo. The most notorious predators of these creatures are the prides of lions that roam the savanna. Savannas also support many species of insects, including ants, beetles, grasshoppers, and termites. The termites may be familiar because of the huge mounds they build. These mounds are important to the savanna ecosystem because they are made of digested plant material. Their construction accelerates the breakdown of these nutrients, thereby enhancing soil quality. The deep and complex passageways in these mounds help carry badly needed rainwater into the soil, instead of the water being carried away or evaporating.

During the dry season, savannas periodically experience large grass fires. The vegetation has evolved ways to be fire resistant, such as rapid regeneration from unburned roots. People have often taken advantage of this process by purposely setting fires to promote new growth that is favorable for grazing animals.

Deserts

Deserts occur where rainfall is very scarce, less than 25 centimeters (10 inches) per year. In warm regions, the problem of scarce water is aggravated by high evaporation and water loss. As a result, deserts have among the lowest rates of plant growth and productivity of any area on earth (see our review of the biosphere). An important consequence is that desert ecosystems will take a longer time to recover from human disturbances, often centuries, than nearly all other ecosystems. The most extreme deserts, including the Sahara of Africa and Gobi of Mongolia, average less than 10 cm (4 inches) of rain per year, sometimes going for years with no rain at all (**FIGURE 4-13**). Some areas of the Atacama Desert in Chile reportedly have never seen recorded rainfall and only occasional cloud cover. As a result, extreme deserts support very little life of any kind. Most extreme deserts occur in a belt that is about 20 to 30 degrees latitude north and south of the equator (see Figure 4-9). This is because rising hot equatorial air produces heavy tropical rains so that when the cooler air sinks to the Earth at about 20 to 30 degrees north and south latitude, it is quite arid.

Semideserts, such as those of the southwestern United States, are less extreme and receive between 10 and 25 cm (4 to 10 inches) of rainfall per year. These extra few inches of rain can support a fairly diverse array of species, usually typified by widely spaced, thorny "desert scrub" vegetation. Desert plants, often called **xerophytes**, have many interesting adaptations that allow them to survive the scarce and unpredictable water supply (**FIGURE 4-14**). Cacti are the most familiar example to many people; water-storing plants such as these are called succulents. Other adaptations can include the following:

- Wide spacing of plants allows maximum moisture per plant.
- Hard exteriors maximize water retention.
- Thorns reduce the consumption of the plants by animals seeking to extract the stored water.
- Deciduous plants shed leaves during dry periods to conserve water.
- Nighttime gas exchange (transpiration) is favored.
- Rapid growth occurs during brief periods of rainfall.
- Very long tap roots, especially in trees, can reach into deep underground water supplies.
- Nearly all perennial plant species can go dormant (a time of reduced photosynthesis) during periods of very high temperature.

FIGURE 4-13 The lack of rain means almost nothing can grow in this part of the Sahara desert in Morocco. © CJ Photography/ShutterStock, Inc.

Annual plants are common in deserts. In these plants, the adult dies and the species survives as seeds that germinate when enough rainfall occurs. Small trees, such as the Joshua tree and mesquite, can occur where water supplies are adequate, but large trees such as the desert cottonwood occur only at oases (springs) or dry riverbeds where deep groundwater supplies are present.

Animal adaptations are often similar to those of plants. Nearly all animals have mechanisms that increase the efficiency by which water is retained. The ability of the camel to go for weeks without drinking is legendary. Desert animals tend to be small, with some exceptions, such as the camel, mule deer, and

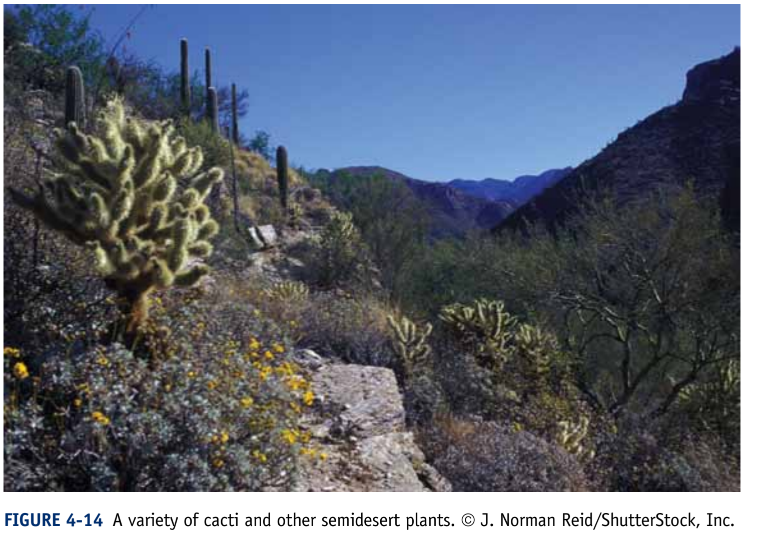


FIGURE 4-14 A variety of cacti and other semidesert plants. © J. Norman Reid/ShutterStock, Inc.

kangaroo. Reptiles are generally more abundant than warm-blooded animals. Reptiles are ectothermic; their behavior regulates their body temperatures. By cooling their body temperatures, they can reduce their energy needs to wait out the dry seasons or low food sources. Also very common is the habit of restricting activity to nighttime, with daytime spent in deep burrows as a means of escaping the heat. Desert rattlesnakes and small rodents illustrate this. Many animals, such as the desert toad, take this one step farther and enter a dormant stage for long periods, becoming revived during the brief periods of rain. It is during this period that reproduction usually occurs.

Temperate Grasslands

Temperate regions with scarce rainfall, about 25 to 75 cm (10 to 30 inches) per year, tend to have grasses and other herbaceous forms as the most prominent plants (**FIGURE 4-15**). Examples include the Great Plains of North America, the pampas of South America, and the steppes of Russia (see Figure 4-9). Tall-grass prairies are grasslands, with plants often standing more than 1 meter tall, of the moister areas. Short-grass prairies consist of clumps of short grasses, such as bunchgrass, that grow in drier regions. The organic matter added annually when the grasses die forms the rich soils of grasslands. The grass roots and the relative lack of rain hold the soils in place. Because of the aridity, grasslands regularly experience fires, especially during the dry season. Trees, although not common, occur locally along stream banks and steep slopes where shade from the sun provides more moisture and protection from fires.

FIGURE 4-15 A rancher and his son look out over their herd of cattle on temperate grasslands. Courtesy of Tim McCabe/USDA Natural Resources Conservation Service.

People have drastically altered much of this biome because economically this is our most important biome. Temperate grasslands provide the richest land in the world for grain crops such as wheat and grazing for sheep, cattle, and other food animals. For example, it is estimated that farming and grazing have drastically modified more than 95% of the original Great Plains biome in the last 200 years. Although many species of grass and the insects supported in the great prairie were lost before they could be counted accurately or their complex relationships understood, modern prairie grass species diversity have been reduced from approximately more than 200 distinct species to about 20 species. In recent years, individual landowners have taken an interest in reintroducing a wider diversity of prairie grasses, but overgrazing still threatens the once highly impressive biodiversity of the Great Plains.

Burrowing animals such as prairie dogs populate grasslands in their natural state, and native herbivorous mammals, for example bison in North America, extensively graze the area. Although grasses have evolved to tolerate significant amounts of grazing, the introduction of nonnative grazers such as cattle has led to overgrazing because, unlike native grazers, they tend to eat the plant faster than it grows. It may not always be obvious that nonnative grazers are more destructive than native species. For instance, why did not the millions of bison that once roamed the American Plains cause just as much impact as some herded cattle do now? In fact, bison could cause localized, temporary damage in the sense of short-term overgrazing, but the bison were migratory and moved on to other areas, allowing the plants to grow back. In addition, bison under natural conditions could be more selective than domesticated cattle in what they ate, focusing, for instance, on just certain tender or tasty parts of a plant. Some bison would also selectively feed on a variety of leaves, twigs, and bark. The overall effect was that bison could live sustainably in their natural environment.

Another problem is the invasion of nonnative grasses, including cheatgrass in the United States, which replace the native grasses after such disturbances as fire and overgrazing. Because of this extensive loss of native grassland plants, substantial efforts have been made toward the ecological restoration of the prairies in North America.

Temperate Forests

Temperate regions with adequate rainfall, 75 to 150 cm (30 to 60 inches) per year, support forests of broad-leaved deciduous trees that show colorful seasonal changes before dropping their leaves (**FIGURE 4-16A**). The seasonal leaf dropping is an adaptation to the very cold winters when water becomes frozen and photosynthesis is difficult or impossible. Examples are found in Europe, parts of Asia, and the eastern United States (Figure 4-9). These regions share many closely related tree species, including the oaks, chestnuts, beeches, and birches, indicating a shared common evolutionary heritage dating geologic periods when the continents were interconnected (see our review of the dynamic Earth and natural hazards). Within the United States, oak and hickory dominate in the Southeast, and beech and maple dominate in the Northeast; however, substantial numbers of conifers (evergreen cone-bearing trees such as pines) occur in many of these forests, mainly as early colonizers of disturbed areas or on poorer soils to which deciduous trees are not well adapted.

These forests lack the spectacular diversity of tropical forests but are still more diverse than coniferous forests. Compared with the tropical rain forests to the south, temperate forests have a well-developed understory vegetation of many shrubs, herbs, ferns,

(a) (b)

FIGURE 4-16 (a) Colorful fall foliage in an eastern U.S. deciduous forest. © Photos.com. (b) Cougar. © AbleStock.

mosses, and small trees because so much light reaches the ground when the tall trees seasonally lose their leaves. In addition, unlike the rain forest, where much animal life is found in the trees, a diverse array of species dwells on the ground. Large herbivores include elk and deer, and carnivores include wolves, cougars, and foxes (**FIGURE 4-16B**).

In the eastern United States, this biome has been drastically modified throughout nearly all of its range. Europeans cleared these forests for farming during the early years of colonization. In some areas, especially the northeastern United States, where the land is no longer farmed, ecological succession is beginning to return the land to its former state. Young temperate forests are now common.

Taiga

Taiga, also called coniferous or boreal forests, occur in a broad belt in northern North America and Asia (Figure 4-9). Very few taigas occur in the Southern Hemisphere because ocean waters mainly occupy these latitudes. Diversity and plant productivity are relatively low because of the stress imposed by long, cold winters with little precipitation. Trees are dominated by conifers (evergreens), which are tolerant of dry, cold conditions (**FIGURE 4-17**). Prominent types of evergreens include spruce, firs, and pines whose needles conserve water and withstand freezing better than do leaves.

FIGURE 4-17 Taiga. © Zastavkin/ShutterStock, Inc.

During the long summer days, plants grow rapidly. Marshes, ponds, and lakes are common, often forming in depressions carved out by the glaciers present in the area just a few thousand years ago.

Common animals of the taiga include herbivores, such as moose, elk, deer, and the snowshoe hare; and carnivores, such as timber wolves, brown bears, lynx, and wolverines. The animals have adapted to the cold in various ways, including exceptionally thick fur and fat storage abilities that help sustain them through the long winters.

Compared with other biomes, the taiga has been less modified by agriculture. One reason is that cleared taiga makes poor cropland. In addition to the cold climate and short growing season, the thin soils are very acidic (pH of 4.5 to 5.0) compared with the soils of grasslands or temperate forests (pH of 6 to 7). The microbial decay of pine needles and other coniferous ground litter produce the acidic soil; however, clear-cutting for timber drastically modifies extensive tracts of the lower-latitude taiga.

Tundra

Arctic tundra occurs in Canada and Eurasia's high northern latitudes, between the taiga and shores of the polar seas (Figure 4-9). As with taiga, little tundra occurs in the Southern Hemisphere because ocean waters occupy these latitudes. Tundra is the low-lying vegetation that occupies an extensive treeless plain whose topsoil is frozen all year except for about 2 months during summer. Below this is permafrost soil, which is frozen all year long. This inhospitable region is not only very cold but also very dry. It receives less than 25 cm (10 inches) per year, or about the same as the desert biome. During the winter, the sun barely rises above the horizon and only for a few hours a day. Few species are able to adapt to such harsh conditions, and so the tundra has relatively low plant species diversity. Not surprisingly, this region also has relatively low plant productivity because of the limited opportunity for photosynthesis.

During the brief summer thaw, the tundra becomes an almost impassable bog, pocketed with countless lakes and streams (**FIGURE 4-18**).

2ND PAGES

Lichens (algae and fungi symbionts), grasses, mosses, and small shrubs are dominant plants. With a growing season of less than 8 weeks, these species must grow and reproduce rapidly. During this period, the tundra teems with life as animals seek to capitalize on these rich but short-lived plant resources. Birds arrive from the south, and animals, including caribou (reindeer), migrate into the area for feeding (Figure 4-18b). The air is filled with billions of insects. More permanent residents include the arctic hare, arctic fox, and snowy owl. Some small rodents such as lemmings survive the winters underground, although they often show drastic population fluctuations. Like the taiga, the harsh nature of this biome has kept it from being modified or occupied by people to any degree.

Alpine tundra occurs in lower latitudes where the altitude is sufficiently high (Figure 4-18). Above the tree line on the slopes of mountains, plant and animal diversity is low. The soil can only support plants similar to those found in the arctic tundra: lichens, grasses, mosses, and shrubs that hug the ground to retain heat and withstand the high winds. The dominant animals are rodents. Mountain goats, elk, sheep, and bears are seasonal residents. Compared with the boggy soil of the arctic tundra, alpine tundra soil is well drained.

Aquatic Biomes

Living conditions in water tend to be much less harsh than on land. The limiting factors in aquatic biomes are different in several important ways. Recall that temperature is a limiting factor on land, but water has many fewer temperature fluctuations. In aquatic environments, the water provides the added benefit of more buoyancy for organisms as support against gravity. The amount of light available in aquatic biomes is a limiting factor in ways that are not experienced on land. Water is a powerful solvent and also readily carries many substances in suspension; these substances, which range from toxins to nutrients, influence life locally. All of these differences occur because water, as a liquid medium, is much denser than the gaseous air. Most importantly, perhaps, getting enough water is not a problem. Living in water eliminates the danger of

(a)

(b)

FIGURE 4-18 (a) The Arctic tundra. Courtesy of U.S. Fish & Wildlife Service. (b) Caribou. © Photodisc.

drying out that most land organisms must face every day. The fact that water in the frozen state floats and expands also is a noteworthy point since this property allows organisms to live in water under the ice even when temperatures are below freezing, and also makes possible life in mud at the bottom of a lake, since most large bodies of water never freeze all the way to the bottom. Not surprisingly, life originated in the shallow oceans and took many millions of years to adapt to land.

Aquatic communities do not divide into distinctive latitudinal biomes like those found on land. Water readily transports heat, and this property enables warm currents, such as the Gulf Stream, to warm large areas even near the poles. This prevents a simple latitudinal gradient from forming. It is the water's salinity that is particularly important in determining what can live in a particular environment. Therefore, ecologists often designate only two aquatic biomes: the marine biome and the freshwater biome (**FIGURE 4-19**).

Marine Biome

Marine water differs from freshwater in containing more dissolved minerals (salts) of various kinds. On average, marine water has about 3.5% salt, mainly sodium chloride, but with many hundreds of other materials as well. The marine biome is the largest biome by far (more than 70% of the Earth's surface) but can be divided relatively easily into the **benthic** zone (on the bottom) and the **pelagic** zone (in the water column). Because water depth and the amount of light affect the distribution of organisms, biologists use them to subdivide these zones into smaller zones.

The pelagic zone includes the relatively shallow water zone over the continental shelves and the deep ocean zone. Pelagic creatures include planktonic organisms (floaters), such as diatoms, and nektonic organisms (swimmers), such as fish, turtles, whales, and squids (**FIGURE 4-20**). Bottom-dwelling organisms can be considered benthic regardless of whether they are attached or not. Benthic creatures include burrowers such as worms, crawlers such as snails, and stationary filter feeders such as barnacles (**FIGURE 4-21**). Benthic communities (Figure 4-19) are further subdivided by depth: littoral (shore), continental shelf, and abyssal (deep sea). Littoral species have adaptations to avoid drying out. For example, barnacles can tightly seal their hard exterior to retain water when the tide goes out. Many other crustaceans dig deeply into the wet sand. The type of shoreline—sandy, muddy, or rocky—subdivides the littoral communities. Deep-water benthic species

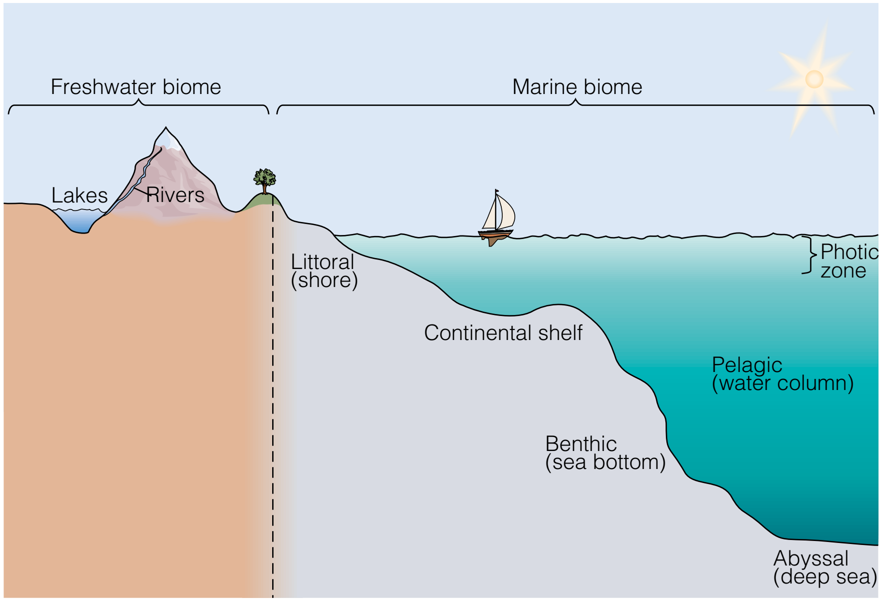
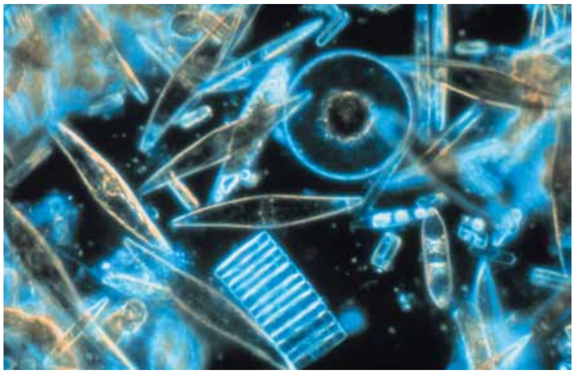


FIGURE 4-19 The two aquatic biomes are freshwater and marine. The marine biome can be divided into benthic and pelagic zones.

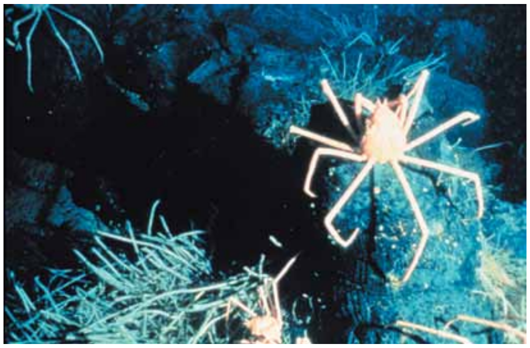


(a)

(b)

FIGURE 4-20 (a) Diatoms are microscopic phytoplankton responsible for much of the ocean's primary production. Courtesy of Dr. Neil Sullivan/ NOAA Corps Collection. (b) French angelfish. Courtesy of Reese/OAR/ National Undersea Research Program (NURP).

(a)



(b)

FIGURE 4-21 (a) This bloodworm lives in salt marsh sediments. Some of these worms are free living, whereas others are tube builders. Courtesy of NOAA, National Estuarine Research Reserve. (b) Spider crabs around a deep sea vent. Courtesy of NOAA, National Undersea Research Program (NURP).

are adapted for withstanding the crushing water pressures found in the deep sea.

The **photic zone** is the upper part of the biome where light penetrates. The depth of this zone depends on the clarity of the water—as shallow as 5 m or as deep as 100 m in tropical waters. The photic zone is the main zone of photosynthesis and therefore is crucial to life in the biome. The photosynthesizing plants, which form the base of the marine food pyramid, are mainly tiny planktonic organisms including diatoms.

Although the marine biome covers nearly three-fourths of the Earth's surface, most of the open ocean supports relatively little life. Much of the ocean is too deep for light to penetrate and drive the photosynthetic food base. The deep ocean is poorly oxygenated, which also restricts the ability of species to live there. The creatures in the deep ocean are largely dependent on the dead organic material that drifts down from above for food. The most productive areas of the ocean are near the shore, where upwelling brings the nutrients from the sea bottom into the photic zone and where nutrients in the ocean flow in from land.

Estuaries are transitional ecosystems between the ocean and freshwater biome. Estuaries, such as the Chesapeake Bay of Maryland and Virginia, occur where rivers and streams flow into the ocean (**FIGURE 4-22**). Five major rivers and over 100 smaller tributaries from six states flow into the Chesapeake Bay. This produces wide fluctuations in the salinity of these waters to which organisms must adapt. On the other hand, the flowing rivers provide a rich supply of nutrients that are rarely rivaled anywhere else on Earth. An estuary's shallow water means tides and waves keep large amounts of nutrients suspended in the water along with oxygen, and light is available for increased photosynthetic activity. As a result, estuaries can support large populations of organisms. Typical animals that

FIGURE 4-22 A satellite image of Chesapeake Bay. Courtesy of Jacques Descloitres, MODIS Land Science Team/NASA.

live in estuaries include oysters, which form reefs that support many other species, such as sponges and barnacles that attach to the reef. The reef traps nutrients, and this attracts many fish and other species. A single oyster reef has been found to support more than 300 species of organisms.

Freshwater Biome

Liquid freshwater covers only 2% of the Earth. The freshwater biome includes both running waters, such as rivers and streams, and standing waters, such as lakes and ponds. In general, rivers and lakes are larger and more permanent than streams and ponds. The faster motion of running waters tends to keep them more highly oxygenated and easier to clean up after being polluted. A river or stream is an open ecosystem in that it derives most of its organic material from upstream or runoff from the land. Many species feed on this detritus. Of special ecological importance is the **riparian zone**. This is the area along the river or stream bank, consisting of cattails, reeds, willows, river birches, and other plants that tolerate high moisture. These plants are very important buffers that reduce flooding impacts and water pollution by absorbing water. They are also critical habitat for many animal species including numerous highly endangered wetland species. Riparian plants are also important for aquatic life: they help protect the water from direct sunlight and reduce heat stress and provide many nutrients for aquatic life in the form of leaves and other detritus.

The slower motion of water in lakes and ponds leads to stratification of the water: the uppermost layer of water has plenty of oxygen while the oxygen decreases with depth. The uppermost layer is also much warmer during the summer and cooler during the winter than the lower layers. There is a sharp boundary, the **thermocline**, between the warm surface water and the colder deeper waters. Summertime swimmers often notice this abrupt transition to cold water when diving. Most of the mixing between the uppermost and deeper layers occurs during seasonal changes known as spring and fall overturn. As with rivers and streams, lakes also have a transitional zone with land, sometimes called the **shore zone**. It functions in the same way as the riparian zone, reducing flooding and heat stress and providing nutrients and critical habitat for many wetland and aquatic species.

As in the ocean, freshwater has two basic life zones: the bottom-dwelling benthic organisms and the swimming pelagic creatures (**FIGURE 4-23**). Familiar benthic organisms include freshwater mussels that filter nutrients from the water and a variety of insects and other crawling or burrowing invertebrates such as

FIGURE 4-23 Beavers are highly dependent on water and can be considered pelagic mammals. © Photodisc.

FIGURE 4-24 Red-eared sliders prefer freshwater habitat with slow-moving water, mud bottoms, and a nice log or other handy place for basking in the sun. © Elena Kouptsova-Vasic/ShutterStock, Inc.

crayfish. Fish, of course, are the most familiar swimming organisms, ranging from catfish that prefer bottom waters to perch and trout that prefer shallower depths. Amphibians are abundant in many freshwaters because they require water to reproduce. Other vertebrates include turtles and a few water-adapted mammals, such as otters, beavers, and muskrats. Algae are usually an especially important type of plant in freshwater ecosystems, although water lilies, various "grasses," and other plants occur as well.

Marshes and swamps are classified as **wetlands**. The ground in these ecosystems are waterlogged or submerged. Because the anaerobic conditions slow organic decomposition, wetlands accumulate rich layers of organic material. Reeds and grasses dominate marshes, whereas trees dominate swamps. Wetlands support a high diversity of organisms and carry out important functions for the biosphere despite the small land area they occupy on Earth. For example, wetlands help filter out pollutants, replenish groundwater supplies, and provide natural flood control. (Saltwater marshes help protect against storm surges.) Wetlands are home to a staggering number of bird, amphibian, insect, and reptile species (**FIGURE 4-24**).

CASE STUDY 4-3

Conservation and the Geography of People

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We see in this chapter how species are not randomly distributed on Earth. As you might suspect, people are not randomly distributed either. Far more people live in some areas, such as near coastlines, than in other areas, such as deserts. Do you suppose that large concentrations of people tend to occupy the same areas that are favorable for high species diversity and density? If true, this has enormous implications for conservation.

This hypothesis seems likely at first glance. We have seen, for example, that biomes such as the desert and tundra have a low productivity. This not only lowers the species diversity and density of these areas, but it also makes them less favorable places for agriculture. In addition, many people prefer to avoid the cold climate of the tundra or the heat of the desert; however, this is only a hypothesis based on the initial evidence presented in this chapter. What does more detailed evidence indicate?

An article that Andrew Balmford and colleagues (2001) published in the journal *Science* analyzed a map of sub-Saharan Africa at a very high degree of resolution. They compared the number of bird, mammal, snake, and amphibian species in each square on a grid with the human population density of that square. They found that, at least for most of Africa, the scenario seems, unfortunately for most nonhuman species, to be true. People do tend to occupy the same areas that are richest in species diversity. This is not entirely because of plant productivity. Other reasons are that people prefer to live in areas of fertile soils, at low elevations, and near water bodies. All of these geographic factors also tend to support relatively high numbers of species.

Another important aspect of species geography is how it relates to the nature reserves that are set aside to protect species. Are these nature preserves geographically selected so that they protect areas of high species diversity? An article by J. Michael Scott and colleagues (2001) published in the journal *Ecological Applications* examined the distribution of more than 2,500 protected areas in the lower 48 states of the United States. They found that less than 6% of the total area is protected and that the reserves were disproportionately located in areas of higher elevations and poor soils. This pattern occurs because land that is set aside for preserves historically has been mountainous land that was not productive for agriculture and was of little **economic value**. As you might suspect, this is bad for the preservation of biodiversity because many areas of high species diversity, such as wetland and riparian habitats, occur only at low elevations. A more effective reserve system must add land that is more representative of all habitats, even if it requires setting aside land that is desirable for agriculture and other human uses.

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Questions

1. Name two state parks in your state. Do you know anything about their history or why they were located where they are?
2. California has the highest population of any state and also the most native plant species. What reasons can you give for its high rank for both population and biodiversity?

study guide

SUMMARY

- Primitive bacteria arose at least 3.5 billion years ago.
- New species originate through natural selection, which passes on beneficial genes.
- Biodiversity is often measured as number of species.
- Rain forest sampling, ecological ratios, and species area curves estimate biodiversity.
- Biomes are suites of communities that share many basic adaptations.
- Climate, especially temperature and rainfall, largely determine biomes.
- The seven terrestrial biomes are tropical forests, savanna, grasslands, deserts, temperate forests, taiga, and tundra.
- The two aquatic biomes are marine and freshwater.

KEY TERMS

amino acids
benthic
biodiversity
biome
Cambrian explosion
chaparral
DNA
economic value
estuaries
eukaryotes
explosion of life
genes
mutation
natural selection
pelagic
photic zone
protocells
riparian zone
shore zone
species
species area curve
species richness
taxonomists
taxonomy
thermocline
wetlands
xerophytes

STUDY QUESTIONS

1. What are amino acids and what is the significance of the amino acid experiments of Miller and Urey and later Fox?
2. Describe the process of evolution by natural selection. How has the physical environment affected the history of life?
3. If a population consisted of a small number of individuals, what effect might natural selection have on its survival?
4. Describe how Mendel's discovery helped in the understanding of variation.
5. Explain two basic causes of variation.
6. Approximately how many genes do humans have? Why is this number significant?
7. What factors may have caused the "explosion of life"?
8. Define biodiversity. Is there only one way to define this concept? How can biodiversity be measured or estimated?
9. Explain why tropical rain forests have such high biodiversity.
10. Do tropical rain forests have fertile soils? Why or why not?
11. Describe four adaptations that plants can have for survival in the desert.
12. How are the two fundamental aquatic biomes recognized?
13. Describe why riparian zones are so important.
14. What is the sharp boundary between warm and cold lake waters?
15. Explain why much of the ocean can be considered a "biological desert."
16. Name the major biomes of Earth. Which biome or biomes do you live in? Would you consider it one of the more favorable biomes for human habitation? Why or why not?

WHAT'S THE EVIDENCE?

1. The authors state that new species may arise as a result of natural selection of individual variation and the isolation of populations. What evidence is given to support this? Can you think of evidence for other causes of evolution? If so, list them.
2. The authors state that the number of species on Earth could be anywhere from 5 to 100 million species. What is the evidence given to support this estimate?

CALCULATIONS

1. If taxonomists have described approximately 1.8 million different species and 56% of these are insects, how many of the described species are insects?
2. If taxonomists have described approximately 1.8 million species but there are actually 30 million different species on Earth, what percentage of the species have taxonomists described?

ILLUSTRATION REVIEW

1. Using Figure 4-8, explain how there can be a polar climate at the equator.
2. In which biomes would you expect to find the type of diversity shown in Figure 4-4a?

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