Ecology

Review

Ecology is the study of the distribution and abundance of organisms, their interactions with other organisms, and their interactions with their physical environment.

The following terms provide a foundation for the study of ecology:

1. A **population** is a group of individuals all of the same species living in the same area. Thus, there are populations of humans, populations of black oaks, and populations of the bacteria *Streptococcus pneumoniae.*
2. A **community** is a group of populations living in the same area.
3. An **ecosystem** describes the interrelationships between the organisms in a community and their physical environment.
4. The **biosphere** is composed of all the regions of the earth that contain living things. This generally includes the top few meters of soil, the oceans and other bodies of water, and the lower ten kilometers of the atmosphere.
5. The **habitat** of an organism is the type of place where it usually lives. A description of the habitat may include other organisms that live there (often the dominant vegetation) as well as the physical and chemical characteristics of the environment (such as temperature, soil quality, or water salinity).
6. The **niche** of an organism describes all the biotic (living) and abiotic (nonliving) resources in the environment used by an organism. When an organism is said to occupy a particular niche, it means that certain resources are consumed or certain qualities of the environment are changed in some way by the presence of the organism.

Population Ecology

Population ecology is the study of the growth, abundance, and distribution of populations. Population abundance and distribution are described by the following terms:

1. The **size** of a population, symbolically represented by *N,* is the total number of individuals in the population.
2. The **density** of a population is the total number of individuals per area or volume occupied. There may be 100 buffalo/km^2 or 100 mosquitos/m^3.
3. **Dispersion** describes how individuals in a population are distributed. They may be clumped (like humans in cities), uniform (like trees in an orchard), or random (like trees in some forests).

4. **Age structure** is a description of the abundance of individuals of each age. It is often graphically expressed in an age structure diagram (Figure 14-1). Horizontal bars or tiers of the diagram represent the frequency of individuals in a particular age group. A vertical line down the center of each tier divides each age group into males and females. A rapidly growing population is indicated when a large proportion of the population is young. Therefore, age structure diagrams that are pyramid-shaped, with tiers larger at the base and narrower at the top, indicate rapidly growing populations. In contrast, age structure diagrams with tiers of equal width represent populations that are stable, with little or no population growth (zero population growth, or ZPG).

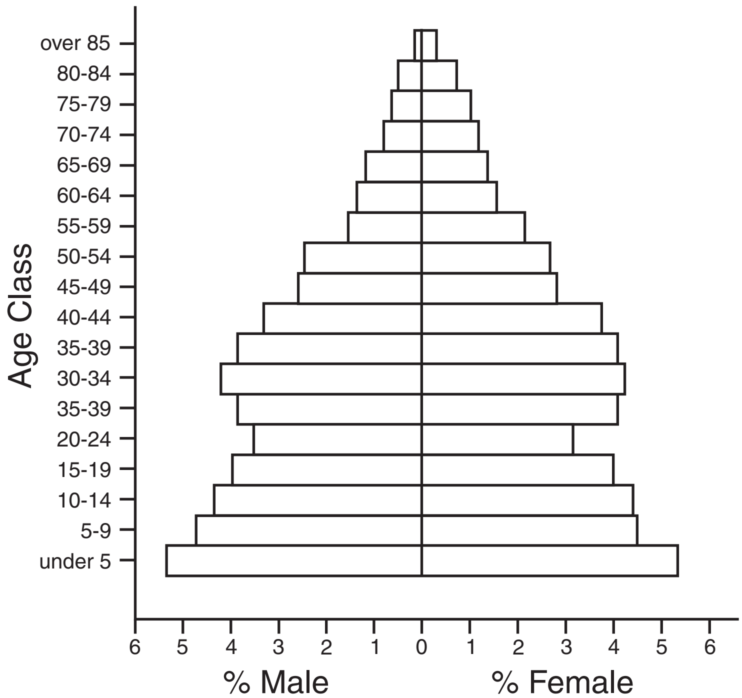

Figure 14-1

5. **Survivorship curves** describe how mortality of individuals in a species varies during their lifetimes (Figure 14-2).

- **Type I** curves describe species in which most individuals survive to middle age. After that age, mortality is high. Humans exhibit type I survivorship.
- **Type II** curves describe organisms in which the length of survivorship is random, that is, the likelihood of death is the same at any age. Many rodents and certain invertebrates (such as *Hydra*) are examples.
- **Type III** curves describe species in which most individuals die young, with only a relative few surviving to reproductive age and beyond. Type III survivorship is typical of oysters and other species that produce free-swimming larvae that make up a component of marine plankton. Only those few larvae that survive being eaten become adults.

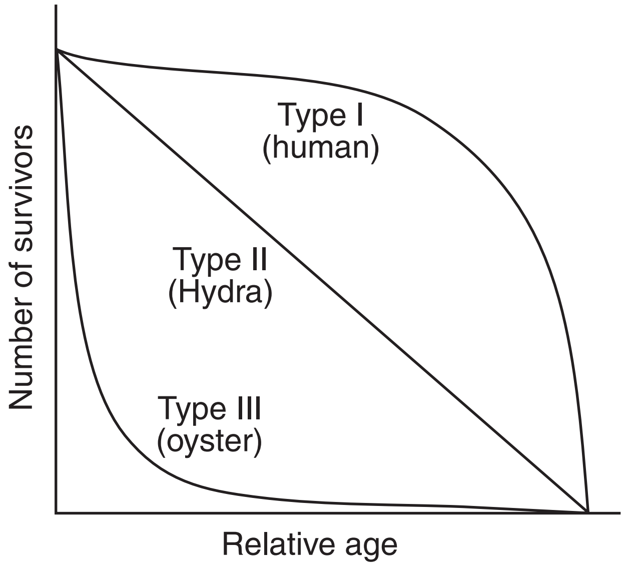

Figure 14-2

The following terms are used to describe population growth:

1. The **biotic potential** is the maximum growth rate of a population under ideal conditions, with unlimited resources and without any growth restrictions. For example, some bacteria can divide every twenty minutes. At that rate, one bacterium could give rise to over a trillion bacteria in ten hours. In contrast, elephants require nearly two years for gestation of a single infant. Even at this rate, however, after two thousand years, the weight of the descendents from two mating elephants would exceed that of the earth. The following factors contribute to the biotic potential of a species:
    - Age at reproductive maturity
    - Clutch size (number of offspring produced at each reproductive event)
    - Frequency of reproduction
    - Reproductive lifetime
    - Survivorship of offspring to reproductive maturity
2. The **carrying capacity** is the maximum number of individuals of a population that can be sustained by a particular habitat.
3. **Limiting factors** are those elements that prevent a population from attaining its biotic potential. Limiting factors are categorized into density-dependent and density-independent factors, as follows:
    - **Density-dependent** factors are those agents whose limiting effect becomes more intense as the population density increases. Examples include parasites and disease (transmission rates increase with population density), competition for resources (food, space, sunlight for photosynthesis), and the toxic effect of waste products. Also, predation is frequently density-dependent. In some animals, reproductive

behavior may be abandoned when populations attain high densities. In such cases, stress may be a density-dependent limiting factor.

- **Density-independent** factors occur independently of the density of the population. Natural disasters (fires, earthquakes, volcanic eruptions) and extremes of climate (storms, frosts) are common examples.

The growth of a population can be described by the following equation:

$$r = \frac{births - deaths}{N}$$

In this equation, r is the **reproductive rate** (or **growth rate**), and N is the population size at the beginning of the interval for which the births and deaths are counted. The numerator of the equation is the net increase in individuals. If, for example, a population of size $N = 1000$ had 60 births and 10 deaths over a one-year period, then r would equal (60 - 10)/1000, or 0.05 per year.

If both sides of the equation are multiplied by N, the equation can be expressed as follows:

$$\frac{\Delta N}{\Delta t} = rN = births - deaths$$

The Greek letter delta (Δ) means "change in." Thus, $\Delta N/\Delta t$ means the change in the number of individuals in a given time interval.

When the reproductive rate, r, is maximum (the biotic potential), it is called the **intrinsic rate** of growth. Note, however, that when deaths exceed births, r will be negative, and the population size will decrease. On the other hand, when births and deaths are equal, the growth rate is zero and the population size remains constant (ZPG).

Population ecologists describe two general patterns of population growth, as follows:

1. **Exponential growth** occurs whenever the reproductive rate is greater than zero. On a graph where population size is plotted against time, a plot of exponential growth rises quickly, forming a **J-shaped** curve (Figure 14-3).

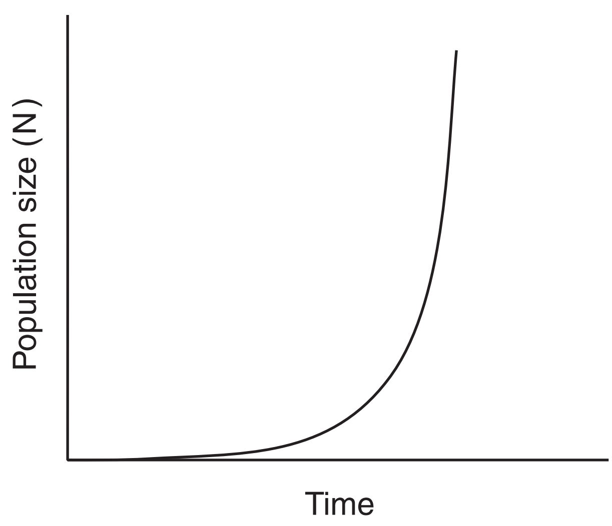

Figure 14-3

2. **Logistic growth** occurs when limiting factors restrict the size of the population to the carrying capacity of the habitat. In this case, the equation for reproductive rate given above is modified as follows:

$$\frac{\Delta N}{\Delta t} = rN\left(\frac{K - N}{K}\right)$$

K represents the carrying capacity. In logistic growth, when the size of the population increases, its reproductive rate decreases until, at carrying capacity (that is, when $N = K$), the reproductive rate is zero and the population size stabilizes. A plot of logistic growth forms an **S-shaped,** or **sigmoid, curve** (Figure 14-4).

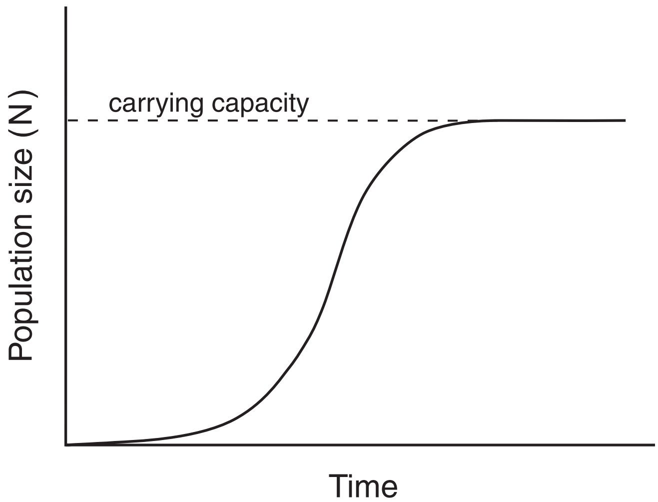

Figure 14-4

Population cycles are fluctuations in population size in response to varying effects of limiting factors. For example, since many limiting factors are density-dependent, they will have a greater effect when the population size is large as compared to when the population is small. In addition, a newly introduced population may grow exponentially beyond the carrying capacity of the habitat before limiting factors inhibit growth (Figure 14-5). When limiting factors do bring the population under control, the population size may decline to levels lower than the carrying capacity (or it may even crash to extinction). Once reduced below carrying capacity, however, limiting factors may ease, and population growth may renew. In some cases, a new carrying capacity, lower than the original, may be established (perhaps because the habitat was damaged by the excessively large population). The population may continue to fluctuate about the carrying capacity as limiting factors exert negative feedback on population growth when population size is large. When population size is small, limiting factors exert little negative feedback, and population growth renews.

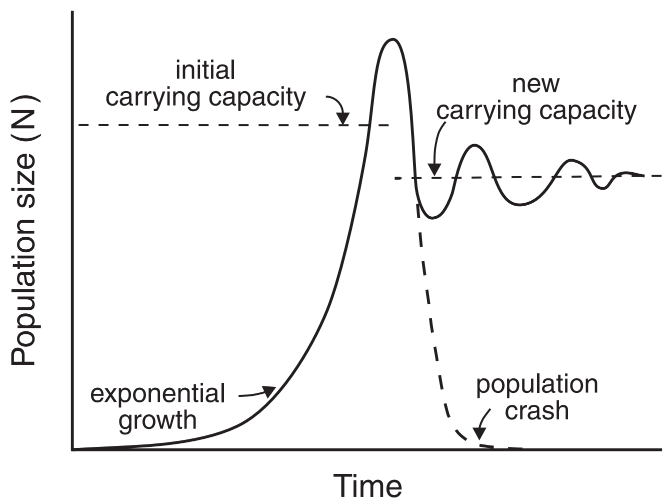

Figure 14-5

Figure 14-6 shows population cycles in the snowshoe hare and its predator the lynx. Since changes in the number of hares is regularly followed by similar changes in the number of lynx, it may appear that predation limits hare populations and that food supply limits lynx populations. Such fluctuation cycles are commonly observed between predator and prey. However, the data in Figure 14-6 indicate only an *association* between the two animals' populations, not that one population *causes* an effect in the other population. In fact, additional data suggest that population size in hares is more closely related to the amount of available food (grass), which, in turn, is determined by seasonal rainfall levels.

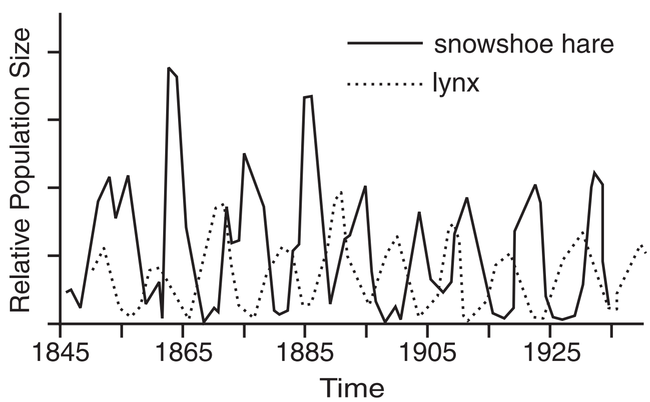

Figure 14-6

Exponential and logistic growth patterns are associated with two kinds of life-history strategies, as follows:

1. An **r-selected species** exhibits rapid growth (J-shaped curve). This type of reproductive strategy is characterized by **opportunistic species,** such as grasses and many insects, that quickly invade a habitat, quickly reproduce, and then die. They produce many offspring that are small, mature quickly, and require little, if any, parental care.

2. A **K-selected species** is one whose population size remains relatively constant (at the carrying capacity, *K*). Species of this type, such as humans, produce a small number of relatively large offspring that require extensive parental care until they mature. Reproduction occurs repeatedly during their lifetimes.

Human Population Growth

About a thousand years ago, the human population began exponential growth. By increasing the carrying capacity of the environment and by immigrating to previously unoccupied habitats, the following factors made exponential growth possible:

1. **Increases in food supply.** By domesticating animals and plants, humans were able to change from a hunter/gatherer lifestyle to one of agriculture. In the last hundred years, food output from agriculture was increased as a result of technological advances made during the industrial and scientific revolutions.
2. **Reduction in disease.** Advances in medicine, such as the discoveries of antibiotics, vaccines, and proper hygiene, reduced the death rate and increased the birth rate.
3. **Reduction in human wastes.** By developing water purification and sewage systems, health hazards from human wastes were reduced.
4. **Expansion of habitat.** Better housing, warmer clothing, easy access to energy (for heating, cooling, and cooking, for example) allowed humans to occupy environments that were previously unsuitable.

Community Ecology

Community ecology is concerned with the interaction of populations. One form of interaction is **interspecific competition** (competition between different species). The following concepts describe the various ways in which competition is resolved:

1. The **competitive exclusion principle** (**Gause's principle**). When two species compete for exactly the same resources (or occupy the same niche), one is likely to be more successful. As a result, one species outcompetes the other, and eventually, the second species is eliminated. The competitive exclusion principle, formulated by G. F. Gause, states that no two species can sustain coexistence if they occupy the same niche.
   - Gause mixed two species of *Paramecium* that competed for the same food. One population grew more rapidly, apparently using resources more efficiently. Eventually, the second species was eliminated.
2. **Resource partitioning.** Some species coexist in spite of apparent competition for the same resources. Close study, however, reveals that they occupy slightly different niches. By pursuing slightly different resources or securing their resources in slightly different ways, individuals minimize competition and maximize success. Dividing up the resources in this manner is called resource partitioning.
   - Five species of warblers coexist in spruce trees by feeding on insects in different regions of the tree and by using different feeding behaviors to obtain the insects.

3. **Character displacement** (**niche shift**). As a result of resource partitioning, certain characteristics may enable individuals to obtain resources in their partitions more successfully. Selection of these characteristics (or characters) reduces competition with individuals in other partitions and leads to a divergence of features, or character displacement.
    - Two species of finches that live on two different Galapagos Islands have similar beaks, both suited for using the same food supply (seeds). On a third island, they coexist, but due to evolution, the beak of each bird species is different. This minimizes competition by enabling each finch to feed on seeds of a different size.
4. **Realized niche.** The niche that an organism occupies in the absence of competing species is its **fundamental niche.** When competitors are present, however, one or both species may be able to coexist by occupying their **realized niches,** that part of their existence where **niche overlap** is absent, that is, where they do not compete for the same resources.
    - Under experimental conditions, one species of barnacle can live on rocks that are exposed to the full range of tides. The full range, from the lowest to the highest tide levels, is its fundamental niche. In the natural environment, however, a second species of barnacle outcompetes the first species, but only at the lower tide levels where desiccation is minimal. The first species, then, survives only in its realized niche, the higher tide levels.

Predation is another form of community interaction. In a general sense, a predator is any animal that totally or partly consumes a plant or another animal. More specifically, predators can be categorized as follows:

1. A **true predator** kills and eats another animal.
2. A **parasite** spends most (or all) of its life living on another organism (the host), obtaining nourishment from the host by feeding on its tissues. Although the host may be weakened by the parasite, the host does not usually die until the parasite has completed at least one life cycle, though usually many more.
3. A **parasitoid** is an insect that lays its eggs on a host (usually an insect or spider). After the eggs hatch, the larvae obtain nourishment by consuming the tissues of the host. The host eventually dies, but not until the larvae complete their development and begin pupation.
4. A **herbivore** is an animal that eats plants. Some herbivores, especially seed eaters (**granivores**), act like predators in that they totally consume the organism. Others animals, such as those that eat grasses (**grazers**) or leaves of other plants (**browsers**), may eat only part of the plant but may weaken it in the process.

Symbiosis is a term applied to two species that live together in close contact during a portion (or all) of their lives. A description of three forms of symbiosis follows:

1. **Mutualism** is a relationship in which both species benefit.
    - Certain acacia trees provide food and housing for ants. In exchange, the resident ants kill any insects or fungi found on the tree. In addition, the ants crop any neighboring vegetation that makes contact with the tree, thereby providing growing space and sunlight for the acacia.

- Lichens, symbiotic associations of fungi and algae, are often cited as examples of mutualism. The algae supply sugars produced from photosynthesis, and the fungi provide minerals, water, a place to attach, and protection from herbivores and ultraviolet radiation. In some cases, however, fungal hyphae invade and kill their symbiotic algae cells. For this and other reasons, some researchers consider the lichen symbiosis closer to parasitism.

2. In **commensalism,** one species benefits, while the second species is neither helped nor harmed.
   - Many birds build their nests in trees. Generally, the tree is neither helped nor harmed by the presence of the nests.
   - Egrets gather around cattle. The birds benefit because they eat the insects aroused by the grazing cattle. The cattle, however, are neither helped nor harmed.
3. In **parasitism,** the parasite benefits from the living arrangement, while the host is harmed.
   - Tapeworms live in the digestive tract of animals, stealing nutrients from their hosts.

Coevolution

In the contest between predator and prey, some prey may have unique heritable characteristics that enable them to more successfully elude predators. Similarly, some predators may have characteristics that enable them to more successfully capture prey. The natural selection of characteristics that promote the most successful predators and the most elusive prey leads to coevolution of predator and prey. In general, coevolution is the evolution of one species in response to new adaptations that appear in another species. Some important examples of coevolution follow:

1. **Secondary compounds** are toxic chemicals produced in plants that discourage would-be herbivores.
   - Tannins, commonly found in oaks, and nicotine, found in tobacco, are secondary compounds that are toxic to herbivores.
2. **Camouflage** (or **cryptic coloration**) is any color, pattern, shape, or behavior that enables an animal to blend in with its surroundings. Both prey and predator benefit from camouflage.
   - The fur of the snowshoe hare is white in winter (a camouflage in snow) and brown in summer (a camouflage against the exposed soil).
   - The larvae of certain moths are colored so that they look like bird droppings.
   - The markings on tigers and many other cats provide camouflage in a forested background. In contrast, the yellow-brown coloring of lions provides camouflage in their savanna habitat.
   - Some plants escape predation because they have the shape and color of the surrounding rocks.

3. **Aposematic coloration** (or **warning coloration**) is a conspicuous pattern or coloration of animals that warns predators that they sting, bite, taste bad, or are otherwise to be avoided.
   - Predators learn to associate the yellow and black body of bees with danger.
4. **Mimicry** occurs when two or more species resemble one another in appearance. There are two kinds of mimicry:
   - **Müllerian mimicry** occurs when several animals, all with some special defense mechanism, share the same coloration. Müllerian mimicry is an effective strategy because a single pattern, shared among several animals, is more easily learned by a predator than would be a different pattern for every animal. Thus, bees, yellow jackets, and wasps all have yellow and black body markings.
   - **Batesian mimicry** occurs when an animal without any special defense mechanism mimics the coloration of an animal that does possess a defense. For example, some defenseless flies have yellow and black markings but are avoided by predators because they resemble the warning coloration of bees.

Ecological Succession

Ecological succession is the change in the composition of species over time. The traditional view of succession describes how one community with certain species is gradually and predictably replaced by another community consisting of different species. As succession progresses, species diversity (the number of species in a community) and total biomass (the total mass of all living organisms) increase. Eventually, a final successional stage of constant species composition, called the **climax community,** is attained. The climax community persists relatively unchanged until destroyed by some catastrophic event, such as a fire.

Succession, however, is not as predictable as once thought. Successional stages may not always occur in the expected order, and the establishment of some species is apparently random, influenced by season, by climatic conditions, or by which species happens to arrive first. Furthermore, in some cases, a stable climax community is never attained because fires or other disturbances occur so frequently.

Succession occurs in some regions when climates change over thousands of years. Over shorter periods of time, succession occurs because species that make up communities alter the habitat by their presence. In both cases, the physical and biological conditions which made the habitat initially attractive to the resident species may no longer exist, and the habitat may be more favorable to new species. Some of the changes induced by resident species are listed below:

1. *Substrate texture* may change from solid rock, to sand, to fertile soil, as rock erodes and the decomposition of plants and animals occurs.
2. *Soil pH* may decrease due to the decomposition of certain organic matter, such as acidic leaves.
3. *Soil water potential,* or the ability of the soil to retain water, changes as the soil texture changes.

4. *Light* availability may change from full sunlight to partly shady, to near darkness as trees become established.
5. *Crowding,* which increases with population growth, may be unsuitable to certain species.

Succession is often described by the series of plant communities that inhabit a region over time. Animals, too, take up residence in these communities but usually in response to their attraction to the kinds of resident plants, not because of any way in which previous animals have changed the habitat. Animals do, however, affect the physical characteristics of the community by adding organic matter when they leave feces or decompose, and the biological characteristics of the community when they trample or consume plants or when they disperse seeds. But because animals are transient, their effects on succession are often difficult to determine.

The plants and animals that are first to colonize a newly exposed habitat are called **pioneer species.** They are typically opportunistic, *r*-selected species that have good dispersal capabilities, are fast growing, and produce many progeny rapidly. Many pioneer species can tolerate harsh conditions such as intense sunlight, shifting sand, rocky substrate, arid climates, or nutrient-deficient soil. For example, nutrient-deficient soils of some early successional stages harbor nitrogen-fixing bacteria or support the growth of plants whose roots support mutualistic relationships with these bacteria.

As soil, water, light, and other conditions change, *r*-selected species are gradually replaced by more stable *K*-selected species. These include perennial grasses, herbs, shrubs, and trees. Because *K*-selected species live longer, their environmental effects slow down the rate of succession. Once the climax community is established, it may remain essentially unchanged for hundreds of years.

There are two kinds of succession, as follows:

1. **Primary succession** occurs on substrates that never previously supported living things. For example, primary succession occurs on volcanic islands, on lava flows, and on rock left behind by retreating glaciers. Two examples follow:
    - *Succession on rock or lava* usually begins with the establishment of lichens. Hyphae of the fungal component of the lichen attach to rocks, the fungal mycelia hold moisture that would otherwise drain away, and the lichen secretes acids which help erode rock into soil. As soil accumulates, bacteria, protists, mosses, and fungi appear, followed by insects and other arthropods. Since the new soil is typically nutrient deficient, various nitrogen-fixing bacteria appear early. Grasses, herbs, weeds, and other *r*-selected species are established next. Depending upon local climatic conditions, *r*-selected species are eventually replaced by *K*-selected species such as perennial shrubs and trees.
    - *Succession on sand dunes* begins with the appearance of grasses adapted to taking root in shifting sands. These grasses stabilize the sand after about six years. The subsequent stages of this succession can be seen on the dunes of Lake Michigan. The stabilized sand allows the rooting of shrubs, followed by the establishment of cottonwoods. Pines and black oaks follow over the next fifty to one hundred years. Finally, the beech-maple climax community becomes established. The entire process may require a thousand years.

2. **Secondary succession** begins in habitats where communities were entirely or partially destroyed by some kind of damaging event. For example, secondary succession begins in habitats damaged by fire, floods, insect devastations, overgrazing, and forest clear-cutting and in disturbed areas such as abandoned agricultural fields, vacant lots, roadsides, and construction sites. Because these habitats previously supported life, secondary succession, unlike primary succession, begins on substrates that already bear soil. In addition, the soil contains a native seed bank. Two examples of secondary succession follow:

   - *Succession on abandoned cropland* (called old-field succession) typically begins with the germination of *r*-selected species from seeds already in the soil (such as grasses and weeds). The trees that ultimately follow are region specific. In some regions of the eastern United States, pines take root next, followed by various hardwoods such as oak, hickory, and dogwood.
   - *Succession in lakes and ponds* begins with a body of water, progresses to a marsh-like state, then a meadow, and finally to a climax community of native vegetation. Sand and silt (carried in by a river) and decomposed vegetation contribute to the filling of the lake. Submerged vegetation is established first, followed by emergent vegetation whose leaves may cover the water surface. Grasses, sedges, rushes, and cattails take root at the perimeter of the lake. Eventually, the lake fills with sediment and vegetation and is subsequently replaced by a meadow of grasses and herbs. In many mountain regions, the meadow is replaced by shrubs and native trees, eventually becoming a part of the surrounding coniferous forest.

Ecosystems

A major goal in the study of ecosystems is to examine the production and utilization of energy. To assist in this goal, plants and animals are organized into groups called **trophic levels** that reflect their main energy source, as follows:

1. **Primary producers** are autotrophs that convert sun energy into chemical energy. They include plants, photosynthetic protists, cyanobacteria, and chemosynthetic bacteria.
2. **Primary consumers,** or herbivores, eat the primary producers.
3. **Secondary consumers,** or primary carnivores, eat the primary consumers.
4. **Tertiary consumers,** or secondary carnivores, eat the secondary consumers.
5. **Detritivores** are consumers that obtain their energy by consuming dead plants and animals (**detritus**). The smallest detritivores, called **decomposers,** include fungi and bacteria. Other detritivores include nematodes, earthworms, insects, and scavengers such as crabs, vultures, and jackals.

Ecological pyramids are used to show the relationship between trophic levels. Horizontal bars or tiers are used to represent the relative sizes of trophic levels, each represented in terms of energy (also called productivity), biomass, or numbers of organisms. The tiers are stacked upon one another in the order in which energy is transferred between levels. The result is usually a pyramid-shaped figure, although other shapes may also result. Several kinds of pyramids are illustrated in Figure 14-7.

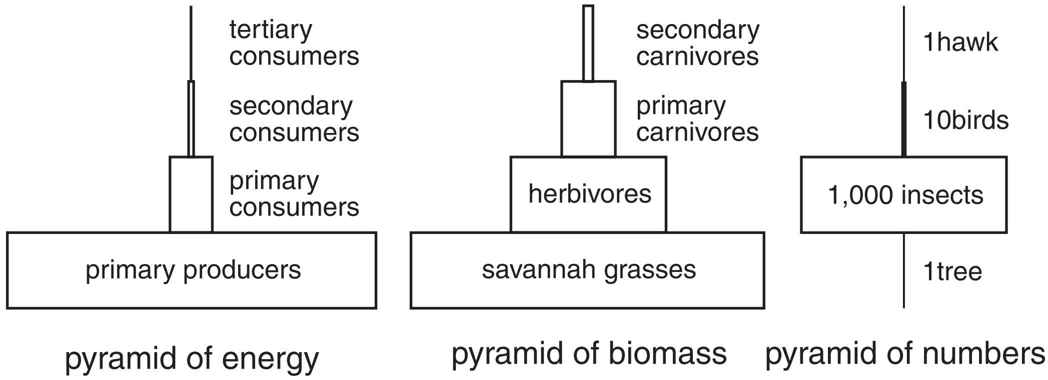

Figure 14-7

Ecological efficiency describes the proportion of energy represented at one trophic level that is transferred to the next level. The relative sizes of tiers in an energy pyramid (or pyramid of productivity) indicate the ecological efficiency of the ecosystem. On average, the efficiency is only about 10%, that is, about 10% of the productivity of one trophic level is transferred to the next level. The remaining 90% is consumed by the individual metabolic activities of each plant or animal, or is transferred to detritivores when they die.

Because ecological efficiency is so low, nearly all domestic animals used for food or work are herbivores. If a carnivore were raised for food or work, the energy required to raise and sustain it would far exceed its value in food or work. The meat consumed by the carnivore would yield a greater return by merely using it directly for human food.

Two kinds of flow charts are often used to show the flow of energy between specific organisms. The arrows used in the flow chart indicate the direction of energy flow.

1. A **food chain** is a linear flow chart of who eats whom. For example, a food chain depicting energy flow in a savanna may look like this:

   grass → zebra → lion → vulture

2. A **food web** is an expanded, more complete version of a food chain. It would show all of the major plants in the ecosystem, the various animals that eat the plants (such as insects, rodents, zebras, giraffes, antelopes), and the animals that eat the animals (lions, hyenas, jackals, vultures). Detritivores may also be included in the food web. Arrows point from all organisms that are eaten to the animals that eat them.

Biogeochemical Cycles

Biogeochemical cycles describe the flow of essential elements from the environment to living things and back to the environment. The following list outlines the major storage locations (reservoirs) for essential elements, the processes through which each element incorporates into terrestrial plants and animals (assimilation), and the processes through which each element returns to the environment (release).

1. **Hydrologic cycle** (water cycle).
   - *Reservoirs:* oceans, air (as water vapor), groundwater, glaciers. (Evaporation, wind, and precipitation move water from oceans to land.)
   - *Assimilation:* plants absorb water from the soil; animals drink water or eat other organisms (which are mostly water).
   - *Release:* plants transpire; animals and plants decompose.
2. **Carbon cycle.** Carbon is required for the building of all organic compounds.
   - *Reservoirs:* atmosphere (as CO_2), fossil fuels (coal, oil), peat, durable organic material (cellose, for example).
   - *Assimilation:* plants use CO_2 in photosynthesis; animals consume plants or other animals.
   - *Release:* plants and animals release CO_2 through respiration and decomposition; CO_2 is released when organic material (such as wood and fossil fuels) is burned.
3. **Nitrogen cycle.** Nitrogen is required for the manufacture of all amino acids and nucleic acids.
   - *Reservoirs:* atmosphere (N_2); soil (NH_4^+ or ammonium, NH_3 or ammonia, NO_2^- or nitrite, NO_3^- or nitrate).
   - *Assimilation:* plants absorb nitrogen either as NO_3^- or as NH_4^+; animals obtain nitrogen by eating plants or other animals. The stages in the assimilation of nitrogen are as follows:

     Nitrogen fixation: N_2 to NH_4^+ by prokaryotes (in soil and root nodules); N_2 to NO_3^- by lightning and UV radiation.

     Nitrification: NH_4^+ to NO_2^- and NO_2^- to NO_3^- by various nitrifying bacteria.

     NH_4^+ or NO_3^- to organic compounds by plant metabolism.
   - *Release:* denitrifying bacteria convert NO_3^- back to N_2 (**denitrification**); detrivorous bacteria convert organic compounds back to NH_4^+ (**ammonification**); animals excrete NH_4^+ (or NH_3), urea, or uric acid.
4. **Phosphorus cycle.** Phosphorus is required for the manufacture of ATP and all nucleic acids. Biogeochemical cycles of other minerals, such as calcium and magnesium, are similar to the phosphorus cycle.
   - *Reservoirs:* rocks. (Erosion transfers phosphorus to water and soil; sediments and rocks that accumulate on ocean floors return to the surface as a result of uplifting by geological processes.)
   - *Assimilation:* plants absorb inorganic PO_4^{3-} (phosphate) from soils; animals obtain organic phosphorus when they eat plants or other animals.
   - *Release:* plants and animals release phosphorus when they decompose; animals excrete phosphorus in their waste products.

Biomes

The biosphere is divided into regions called **biomes** that exhibit common environmental characteristics. Each biome is occupied by unique communities or ecosystems of plants and animals that share adaptations which promote survival within the biome. Following is a list of the major biomes and a summary of their characteristics:

1. **Tropical rain forests** are characterized by high temperature and heavy rainfall. The vegetation consists predominately of tall trees that branch only at their tops, forming a spreading canopy that allows little light to reach the forest floor. **Epiphytes** (plants that live commensally on other plants) and vines commonly grow on the trees, but due to lack of light, little grows on the forest floor.
2. **Savannas** are grasslands with scattered trees. Because savannas are tropical, they are subject to high temperatures. However, they receive considerably less water than rain forests.
3. **Temperate grasslands** receive less water and are subject to lower temperatures than are savannas. The North American prairie is an example.
4. **Temperate deciduous forests** occupy regions that have warm summers, cold winters, and moderate precipitation. Deciduous trees shed their leaves during the winter, an adaptation to poor growing conditions (short days and cold temperatures).
5. **Deserts** are hot and dry. Growth of annual plants is limited to short periods following rains. Other plants have adapted to the hostile conditions with leathery leaves, deciduous leaves, or leaves reduced to spines (cacti). Many animals have thick skins, conserve water by producing no urine or very concentrated urine, and restrict their activity to nights.
6. **Taigas** are characterized by coniferous forests (pines, firs, and other trees with needles for leaves). Winters are cold, and precipitation is in the form of snow.
7. **Tundras** are subject to winters so cold that the ground freezes. During the summer, the upper topsoil thaws, but the deeper soil, the **permafrost,** remains permanently frozen. During the summer, the melted topsoil supports a grassland type community consisting of grasses, sedges, and other vegetation tolerant of soggy soils.
8. **Fresh water biomes** include ponds, lakes, streams, and rivers.
9. **Marine biomes** include estuaries (where oceans meet rivers), intertidal zones (where oceans meet land), continental shelves (the relatively shallow oceans that border continents), coral reefs (masses of corals that reach the ocean surface), and the pelagic ocean (the deep oceans).

Human Impact on the Biosphere

Human activity damages the biosphere. Exponential population growth, destruction of habitats for agriculture and mining, pollution from industry and transportation, and many other activities all contribute to the damage of the environment. Some of the destructive consequences of human activity are summarized as follows:

1. **Greenhouse effect.** The burning of fossil fuels and forests increases CO_2 in the atmosphere. Increases in CO_2 cause more heat to be trapped in the earth's atmosphere. As a result, global temperatures are rising. Warmer temperatures could raise sea levels (by melting more ice) and decrease agriculture output (by affecting weather patterns).
2. **Ozone depletion.** The ozone layer forms in the upper atmosphere when UV radiation reacts with oxygen (O_2) to form ozone (O_3). The ozone absorbs UV radiation and thus prevents it from reaching the surface of the earth where it would damage the DNA of plants and animals. Various air pollutants, such as chlorofluorocarbons (CFCs), enter the upper atmosphere and break down ozone molecules. CFCs have been used as refrigerants, as propellants in aerosol sprays, and in the manufacture of plastic foams. When ozone breaks down, the ozone layer thins, allowing UV radiation to penetrate and reach the surface of the earth. Areas of major ozone thinning, called **ozone holes,** appear regularly over Antarctica, the Arctic, and northern Eurasia.
3. **Acid rain.** The burning of fossil fuels (such as coal) and other industrial processes release into the air pollutants that contain sulfur dioxide and nitrogen dioxide. When these substances react with water vapor, they produce sulfuric acid and nitric acid. When these acids return to the surface of the earth (with rain or snow), they kill plants and animals in lakes and rivers and on land.
4. **Desertification.** Overgrazing of grasslands that border deserts transform the grasslands into deserts. As a result, agricultural output decreases, or habitats available to native species are lost.
5. **Deforestation.** Clear-cutting of forests causes erosion, flooding, and changes in weather patterns. The slash-and-burn method of clearing tropical rain forests for agriculture increases atmospheric CO_2, which contributes to the greenhouse effect. Because most of the nutrients in a tropical rain forest are stored in the vegetation, burning the forest destroys the nutrients. As a result, the soil of some rain forests can support agriculture for only one or two years.
6. **Pollution.** Air pollution, water pollution, and land pollution contaminate the materials essential to life. Many pollutants do not readily degrade and remain in the environment for decades. Some toxins, such as the pesticide DDT, concentrate in plants and animals. As one organism eats another, the toxin becomes more and more concentrated, a process called **biological magnification.** Other pollution occurs in subtle ways. A lake, for example, can be polluted with runoff fertilizer or sewage. Abundant nutrients, especially phosphates, stimulate **algal blooms,** or massive growths of algae and other phytoplankton. The phytoplankton reduce oxygen supplies at night when they respire. In addition, when the algae eventually die, their bodies are consumed by detrivorous bacteria, whose growth further depletes the oxygen. The result is massive oxygen starvation for many animals, including fish and invertebrates. In the end, the lake fills with carcasses of dead animals and plants. The process of nutrient enrichment in lakes and the subsequent increase in biomass is called **eutrophication.** When the process occurs naturally, growth rates are slow and balanced. But with the influence of humans, the accelerated process often leads to the death of fish and the growth of anaerobic bacteria that produce foul-smelling gases.
7. **Reduction in species diversity.** As a result of human activities, especially the destruction of tropical rain forests and other habitats, plants and animals are apparently becoming extinct at a faster rate than the planet has ever previously experienced. If they were to survive, many of the disappearing plants could become useful to humans as medicines, foods, or industrial products.