Chapter 11

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.

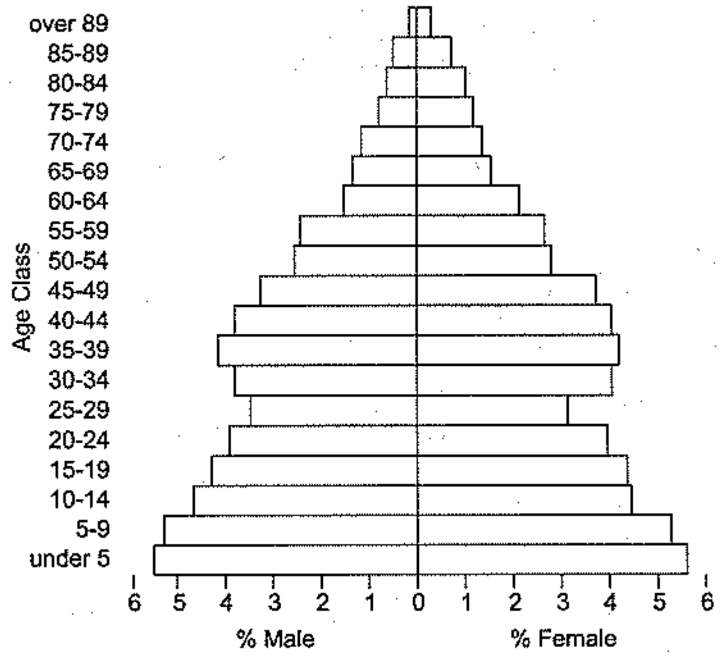
The following terms provide a foundation for the study of ecology:

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 10 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 a forest).
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 11-1). 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).



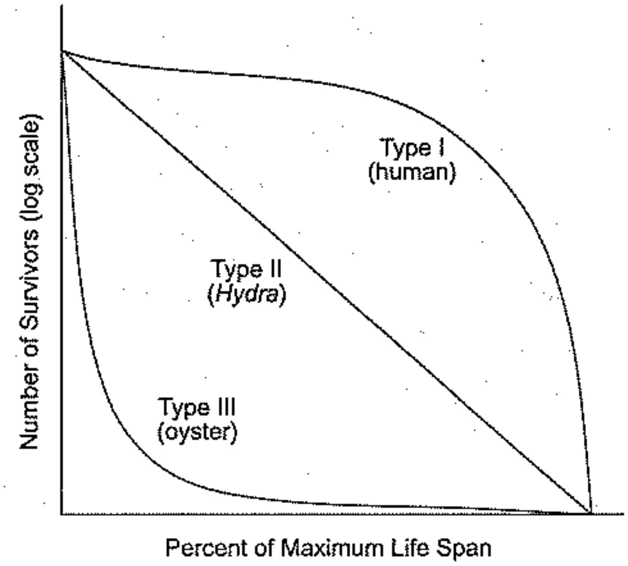
Age Structure

Figure 11-1

5. **Survivorship curves** describe how mortality of individuals in a species varies during their lifetimes (Figure 11-2):
   - **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.

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 20 minutes. At that rate, one bacterium could give rise to over a trillion bacteria in 10 hours. In contrast, elephants require nearly two years for gestation of a single infant. Even at this rate, however, after 2,000 years, the weight of the descendants 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



Survivorship Curves

Figure 11-2

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, nesting materials, and space for growth or reproduction, including nesting sites and 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, and volcanic eruptions) and extremes of climate (storms, floods, and frosts) are common examples.

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

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

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 $N = 1{,}000$ had 60 births and 10 deaths over a one-year period, then r would equal $\frac{60-10}{1{,}000}$, or 0.05 per year.

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

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

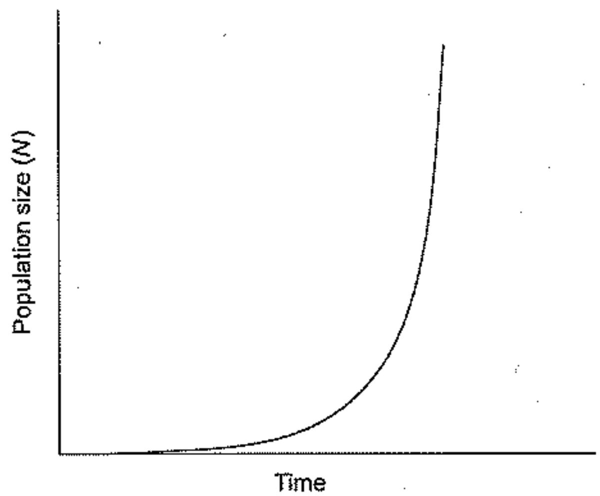
The Greek letter delta (Δ) means "change in." Thus, $\frac{\Delta N}{\Delta t}$ means the change in the number of individuals in a given time interval. The expression can also be written in calculus terms, using $\frac{dN}{dt}$ for $\frac{\Delta N}{\Delta t}$. (Don't let the calculus expression intimidate you; for our purposes, the two expressions are essentially the same.)

$$\frac{dN}{dt} = r_{max}N$$

Here the reproductive rate, r_{max}, is maximum and so represents the biotic potential. It is called the **intrinsic rate** of growth. Note 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.

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

1. **Exponential growth** occurs whenever the reproductive rate, as described by the equation $\frac{dN}{dt} = r_{max}N$, 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 11-3):



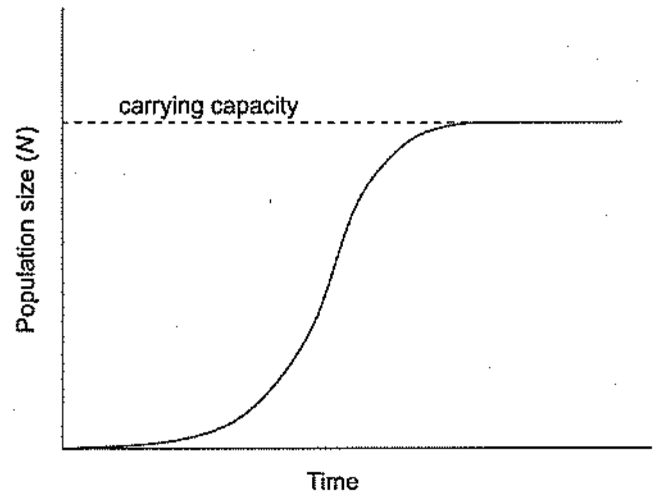
Exponential Population Growth

Figure 11-3

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:

$$\frac{dN}{dt} = r_{max}N\left(\frac{K-N}{K}\right)$$

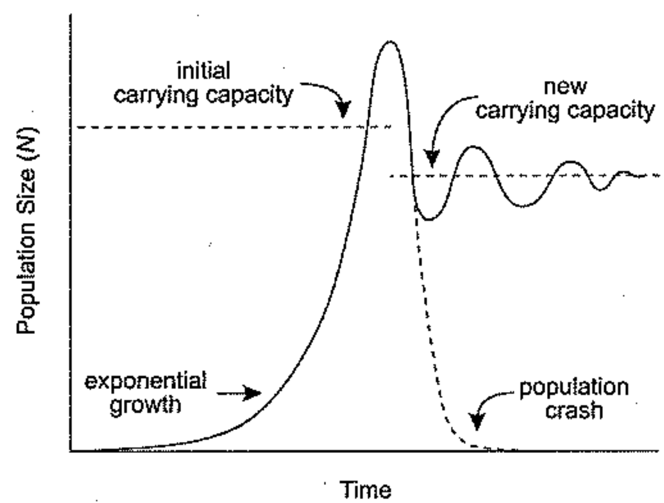
   K represents the carrying capacity. In logistic growth, when the size of the population increases, its reproductive rate decreases until, at carrying capacity (that is, when $N = K$), the reproductive rate is zero and the population size stabilizes. A plot of logistic growth forms an **S-shaped**, or **sigmoid**, curve (Figure 11-4):



Logistic Population Growth

Figure 11-4

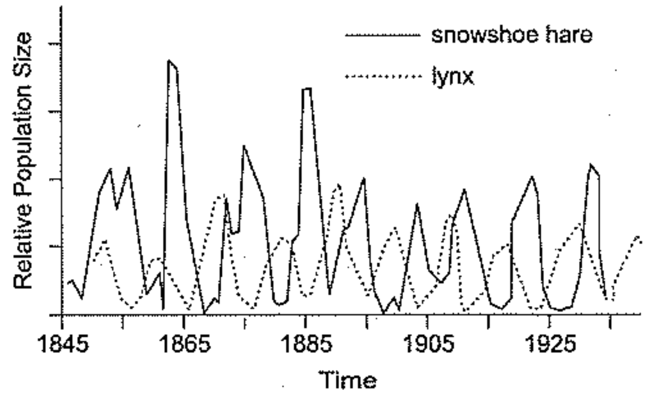
Population cycles are fluctuations in population size in response to varying effects of limiting factors. For example, since many limiting factors are density-dependent, they will have a greater effect when the population size is large as compared to when the population size is small. In addition, a newly introduced population may grow exponentially beyond the carrying capacity of the habitat before limiting factors inhibit growth (Figure 11-5). 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 the population size is large. When the population size is small, limiting factors exert little negative feedback and population growth renews.



Effects of Carrying Capacity on Population Growth

Figure 11-5

Figure 11-6 shows population cycles in the snowshoe hare and its predator, the lynx. Since changes in the number of hares are 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 11-6 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 the population size in hares is more closely related to the amount of available food (grass), which, in turn, is determined by seasonal rainfall levels.



Population Cycles

Figure 11-6

The **life history** of an organism describes its strategy for maximum fitness. Reproductive success, a measure of fitness, depends upon four variables: the age of reproductive maturity, the frequency of reproduction, the number of offspring per reproductive event, and how long the organism lives. There are various ways in which these four variables can combine to maximize fitness given the resources available under different environmental conditions. In general, two major strategies emerge, 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** exhibits logistic growth (S-shaped curve), and the size of a mature population 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 half-century, food output from agriculture increased as a result of various technological advances, including the development and application of fertilizers and pesticides and the construction of irrigation systems.
2. **Reduction in disease.** Advances in medicine, such as the discoveries of antibiotics, vaccines, and proper hygiene, reduced the death rate and increased the rate of growth.

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, and 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 biologist G. F. Gause, states that no two species can sustain coexistence if they occupy the same niche when resources are limiting.
   - 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. **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.
4. **Character displacement (niche shift).** As a result of resource partitioning, certain characteristics may enable individuals to obtain resources in their partitions more successfully. Selection for these characteristics 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 Galápagos 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.

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 other animals.
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 another insect or a 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, 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. A shorthand notation for describing the relationship is provided, where a "+" indicates that one individual benefits, a "–" indicates one is harmed, and a "0" indicates no effect.

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 from ultraviolet radiation. In some cases, however, fungal hyphae invade and kill some of their symbiotic algae cells. For this and other reasons, some researchers consider the lichen symbiosis closer to parasitism.
   - **Termites** harbor protists and bacteria for a mutualistic association, where termites supply wood (mostly cellulose) to the microbes in exchange for the breakdown of that wood. Protists are single-celled, eukaryotic organisms living inside the digestive tract of the termite, while the bacteria, living on or inside the protists, produce various **cellulases**, enzymes that break down wood.
   - The **digestive floras** are the bacteria and protists that live in the digestive tracts of animals. The flora receives food and a protected habitat. In exchange, the flora helps digest otherwise indigestible foods such as cellulose, produces vitamin K, prevents (by competitive exclusion) the growth of harmful bacteria, and carries out other beneficial functions. To digest cellulose and other polysaccharides, the flora carries out fermentation, the products of which provide the flora and the host with a source of energy and nutrients. Some mammals, the ruminants, which include cows, goats, and deer, have a specialized four-chambered stomach, the **rumen**, which serves as a fermentation chamber. Ruminants regurgitate their food for additional chewing to more completely break down food for more thorough fermentation. The digestive systems of other herbivorous mammals, such as rabbits and horses, lack a rumen and are less efficient. The digestive flora are part of a larger community that inhabits digestive tracts—the microbiome. In addition to mutualistic organisms, microbiota may include commensal, parasitic, and pathogenic organisms.
   - **Mycorrhizae** are mutualistic associations of certain fungi with the roots of plants. Plants provide carbohydrates to the fungus, and the filaments of the fungus increase the surface area of the roots, facilitating the absorption of water and minerals, especially phosphorus. Mycorrhizae are common; they form with most flowering plants and some conifers, ferns, and mosses.
2. In **commensalism**, one species benefits, while the second species is neither helped nor harmed (+, 0).
   - 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 other cases, two species may evolve so that mutual benefits increase. 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. In many cases, metabolic adaptations have evolved in herbivores that allow them to tolerate these toxins. For example, monarch butterflies eat milkweed plants whose toxins accumulate in the bodies of the butterflies and serve to protect them from their predators.
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.
5. **Pollination** of many kinds of flowers occurs as a result of the coevolution of finely tuned traits between the flowers and their pollinators.
   - Pollen from flowers of the *Yucca* plant is collected by yucca moths. Pollination is accomplished when the moths roll the pollen into a ball, carry it to another *Yucca* plant, and deposit it on the stigma, the pollen receptor of a flower. The moth also deposits its eggs into some of the flower's ovules, but only about a third of the flower's seeds are eaten by the moth larvae after hatching from the eggs. There are no other pollinators for *Yucca* and no other hosts for yucca moth egg laying.
   - Red, tubular flowers with no odor have coevolved with hummingbirds, who are attracted to red and have long beaks and little sense of smell. The flowers provide a copious amount of nectar in exchange for the transfer of their pollen to other flowers.

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 that 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 partial shade 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 affect 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 that 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 50 to 100 years. Finally, the beech-maple climax community becomes established. The entire process may require 1,000 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 community of viable native seeds called the *soil 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.

The Flow of Energy in Ecosystems

On average, only about 1% of the solar energy that reaches the surface of the earth is converted into organic matter. How that energy gets distributed to all the living things in an ecosystem helps us understand how ecosystems work.

Two types of flow charts demonstrate how energy flows through an ecosystem, showing who eats whom. The arrows used in these flow charts 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, and antelopes), and the animals that eat the animals (lions, hyenas, jackals, and vultures). Detritivores may also be included in the food web. Arrows connect all organisms that are eaten to the animals that eat them, pointing in the direction of energy flow.

Another way to illustrate energy flow and the production and utilization of energy is to organize plants and animals into groups called **trophic levels**. In general, organisms are either **autotrophs** that are able obtain energy from light or inorganic material or **heterotrophs** that must consume other organisms or organic material for their source of energy. Each of the following groups represents a trophic level that reflects its main energy source:

1. **Primary producers** are photoautotrophs that convert sun energy into chemical energy. They include plants, photosynthetic protists, and cyanobacteria. Primary producers can also be represented by chemoautotrophs when the sources of energy are inorganic substances.
2. **Primary consumers,** or herbivores, are heterotrophs that eat the primary producers.
3. **Secondary consumers,** or primary carnivores, are heterotrophs that eat the primary consumers.
4. **Tertiary consumers,** or secondary carnivores, are heterotrophs that eat the secondary consumers.
5. **Detritivores** are heterotrophs 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.

Chemoautotrophs are the primary producers for hydrothermal vent communities where seawater comes in contact with super-hot rock, H_2S, and O_2. In these unique communities, chemoautotrophic prokaryotes live mutualistically in specialized organs of large (1.5 m long) tube worms. The tube worms absorb dissolved H_2S and O_2 and transport it to the prokaryotes, where they use the energy from H_2S to produce carbohydrates.

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 ecological pyramids are illustrated in Figure 11-7.

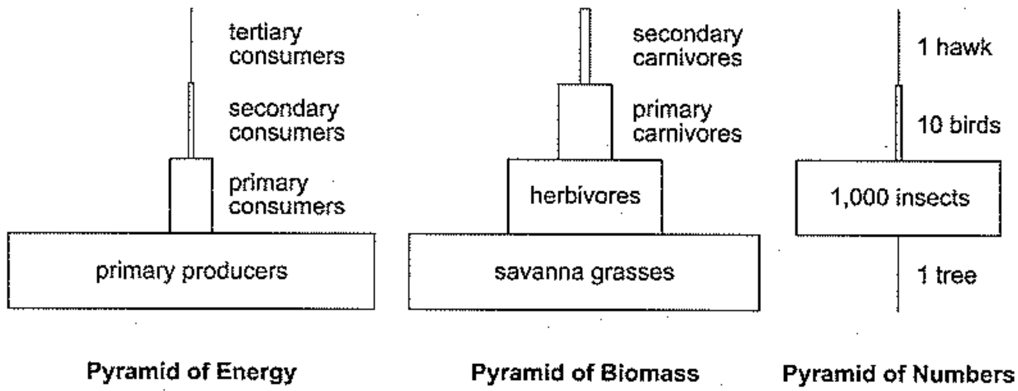


Figure 11-7

Primary productivity in an ecosystem is the amount of organic matter produced through photosynthetic (or chemosynthetic) activity per unit of time. Components of primary productivity include the following (note that the term *rate* means per unit time):

1. **Gross primary productivity (GPP)** is the rate at which producers acquire chemical energy before any of this energy is used for metabolism.
2. **Net primary productivity (NPP)** is the rate at which producers acquire chemical energy less the rate at which they consume energy through respiration. NPP represents the biomass available to herbivores.
3. **Respiratory rate (R)** is the rate at which energy is consumed through respiration (and other metabolic activities necessary to maintain life). This energy, much of it in the form of ATP, is ultimately lost as heat.

These components are related by the following equation.

$$NPP = GPP - R$$

NPP, generated at the bottom tier of the ecological pyramid of energy, supports all of the tiers above it. Energy stored in NPP is transferred to herbivores when they eat the primary producers. The herbivores, then, use that energy for respiration (and other activities necessary for life), and the remainder is used for growth, increasing biomass. Each successive tier above the herbivores, that is, the secondary and tertiary consumers, repeats the process, using the energy in the biomass of tiers below them to provide for respiration and growth.

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.

It is important to note that much of the energy for respiration and other metabolic activities is ultimately lost as heat. Heat is energy that cannot be harnessed by organisms to do work and, thus, represents energy lost from the ecosystem. Ultimately, all energy originally gained through NPP is lost as heat. Thus, in contrast to nutrients and other forms of matter (discussed later in this chapter), heat cannot be recycled. Remember: Energy flows, matter recycles.

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.

Species Diversity and Trophic Interactions

Certain species in a community can heavily influence the dynamics of that community:

1. The **dominant species** is the most abundant species or the species that contributes the greatest biomass to a community. A species becomes dominant in its particular habitat because, of all other species in the community, it is best able to compete for resources or escape predators or disease.
2. A **keystone species** is one that has a strong influence on the health of a community or ecosystem. Removal of a keystone species results in dramatic changes in the makeup of species that comprise other trophic levels.
   - Sea otters, a keystone species, eat sea urchins, and sea urchins eat kelp. When otter population size drops along the Pacific coast of North America due to excessive hunting (by humans) or predation (by killer whales), the number of urchins increases dramatically. In turn, kelp populations plummet, and the fish and marine invertebrates that lived in the kelp beds disappear.
   - The grey wolf, a keystone species, eats elk, deer, coyotes, and other large mammals. Because of threats to livestock, wolves were hunted to extinction in most U.S. states. In their absence, elk and deer populations exploded, vegetation was overgrazed, and erosion of the landscape ensued. Coyotes also flourished, and as a result, populations of smaller mammals diminished. When wolves were reintroduced to Yellowstone National Park, elk, deer, and coyote populations declined and much vegetation returned. Numbers of beavers, hares, and other small herbivores increased, camouflaged by the restored vegetation (especially near lakes and streams). These small herbivores, as well as the carcasses abandoned by wolves, attracted eagles, wolverines, and other meat-eating animals. Consequently, the return of wolves to Yellowstone restored the balance of living things that were historically native to the ecosystem.
3. An **invasive species** is an introduced species that proliferates and displaces native species because it is a better competitor or because its natural predators or pathogens are absent. Most invasive species have been accidently or deliberately introduced by humans.
   - **Kudzu** is a climbing vine that grows throughout the southeastern United States. It coils over trees and other vegetation, killing them by preventing sunlight from reaching leaves. Native to Asia, it was introduced to the United States at the first World's Fair in 1876.
   - **Dutch elm disease** is caused by a fungus that attacks and kills elm trees. The fungus is spread by a bark beetle. The native habitat of the fungus is uncertain, but it was introduced accidently in Europe and the United States in the early twentieth century.
   - **Potato blight** is caused by a fungus-like protist. Fungal spores overwinter on tubers (potatoes), germinate, and spread though plant tissues, eventually producing new spores on the leaves. Spores are dispersed by wind or water. Potatoes, native to South America, were introduced (deliberately) to Europe in the sixteenth century, where they remained disease-free until the middle of the nineteenth century. The fungus, possibly originating in Central or South America, first appeared in the United States, where spores were dispersed by wind, then delivered (accidently) to Europe on diseased potatoes.
   - **Smallpox** is an infectious human disease introduced to North America by Europeans in the sixteenth century. Because populations originating in the Western Hemisphere lacked any natural immunity, the disease caused widespread devastation among the Native American populations.

A number of factors influence the number and size of trophic levels in an ecosystem:

1. **Size of bottom trophic level.** Because primary producers provide the initial source of energy to the ecosystem, their numbers and the amount of biomass they generate govern the size and makeup of all other trophic levels. Thus, an ecosystem based on a small tier of primary producers cannot sustain many tiers above it.

2. **Efficiency of energy transfer between trophic levels.** On average, there is a 10% decline (that is, an exponential decline) in biomass and the energy it provides as it passes up through the tiers of the pyramid of energy. Thus, the number of trophic levels that can be supported declines rapidly. However, more efficient ecosystems, with higher photosynthetic efficiency, can generate longer food chains and more complex food webs. Such ecosystems occur in tropical rain forests.
3. **Stability of trophic levels.** In ecosystems with long food chains, top trophic levels are more susceptible to damage because there are more levels below them that can be weakened by environmental changes.
4. **Requirements of top predators.** The top predators that occupy the uppermost tier are usually large animals with proportionately large energy requirements. Thus, the size of top tiers is limited both because there is less biomass available at the top of the pyramid and because the individual energy requirements of the animals are large.

The size of trophic levels can also be regulated by interactions between the levels. Two interaction models are described:

1. A **bottom-up model** describes how changes in the structure of trophic levels are regulated by changes in the *bottom* trophic level. When primary productivity is low, few trophic levels above it can be supported. In the absence of predation by herbivores, primary producers expand without challenge. At some point, however, herbivores begin to respond to the increasing availability of primary production, and herbivore populations expand. As herbivore numbers increase, more primary producers are consumed, and their growth is checked. Then, predators respond to increasing numbers of herbivores, limiting herbivore growth, which, in turn, allows growth of primary producers to increase once again.
2. A **top-down model** describes how changes in the structure of trophic levels are regulated by changes in the *top* trophic level. The model is essentially the opposite of the bottom-up model. For example, sea otters occupying the top tier (as a keystone species, described above) limit the number of sea urchins. With sea urchins in check, the bottom trophic level of kelp forests increases in numbers. In contrast, if sea otters are removed, sea urchins increase and kelp forests dissipate. Thus, sea otters, comprising the top trophic tier, regulate the population size of the kelp, the bottom tier. Many examples of the top-down model are created by humans when they remove top predators (often keystone species) by overhunting or habitat destruction.

The **biodiversity** of an ecosystem is expressed as a function of the number of species, niches, and trophic levels in the ecosystem and the complexity of its food web. In addition to the interactions between species and trophic levels described above, a number of factors influence biodiversity:

1. **Climate** is a strong determinant of biodiversity. The amount, variability, and form of water (precipitation as rain or snow, presence of rivers or other bodies of water) strongly influence the abundance and type of primary producers and the number of species primary production can support. The range of temperatures between night and day, as well as throughout the year, is equally important.
2. **Latitude** is strongly correlated with climate, but it also determines solar energy exposure. Solar energy exposure controls the extent of photosynthesis and the biomass of the primary producers. Areas at the equator receive more solar energy than those at the poles. Also, because seasonal variations are minimized at lower latitudes (regions close to the equator), more constant environmental conditions are often able to support more species.
   - Tropical ecosystems are highly diverse, having many species but with smaller numbers of each species. In contrast, polar ecosystems have few species but with many individuals of those species.
3. **Habitat size and diversity** influence how many different kinds of organisms can be supported. The larger an ecosystem, the more likely that it contains greater kinds of soil texture, soil chemistry, and variations in the slope of the terrain. More diverse habitats support a greater variety of species.
4. **Elevation** also influences biodiversity. Temperature is strongly correlated with elevation, decreasing as elevation increases. Precipitation often increases with elevation, although the water content of snow deposited at higher elevations is only available to plants after it has melted.
   - Coniferous forests heavily laden with snow during the winter months become productive only after the snow has melted.

Simpson's Diversity Index can be used to calculate the biodiversity of a community:

Diversity Index $= 1 - \sum\left(\frac{n}{N}\right)^2$, where n = the number of individuals in a species population and N = the total number of all individuals among all species.

To calculate this index, calculate $\frac{n}{N}$ for each species and square it. Add together all of these values for each species and subtract the sum from 1. Values of D vary from 0 to 1, with higher numbers indicating greater diversity.

The **stability** of an ecosystem increases with increases in biodiversity. This occurs because, in a highly diverse system, disturbances may adversely affect only a few of the components (species) of the ecosystem, while one or more unaffected components can replace them. In systems with low biodiversity, disturbances may have a more permanent effect. Disturbances that threaten the stability of ecosystems include fires, floods, disease, and the various effects caused by humans (discussed in "Human Impact on Ecosystems," later in this chapter). Some environmental disturbances are extremely disruptive, however, and have major effects on ecosystems and the biosphere, as follows:

1. **El Niño** (El Niño–Southern Oscillation) is an atmospheric and oceanic phenomenon that precedes changes in weather patterns throughout the biosphere. During normal atmospheric conditions (La Niña), trade winds over the equatorial Pacific blow strongly from east to west. As the wind blows, it pushes surface water in the same direction, blowing it away from the west coast of South America. In its place, cold, nutrient-rich water from below rises to the surface (a process called **upwelling**) along the South American coastline. The nutrients promote a bottom-up ecological effect, stimulating algae growth first, then marine herbivores and fish. Sea birds eat the fish. But when an El Niño occurs, the trade winds and upwelling stop, algae populations decline, and the collapse of the local food web and local fish industry ensues. In contrast, many marine invertebrate populations skyrocket as they thrive on the carcasses of dead sea animals. The effects of El Niño stretch globally, increasing or decreasing rainfall from Peru to Australia, Indonesia, and the southwestern United States.
2. **Meteor impacts** and large **volcanic eruptions** have historically triggered global changes in atmospheric conditions. Both increase the amount of particulate matter in the atmosphere, reducing the amount of solar radiation reaching the surface of the earth. A decrease in primary production follows, and that initiates a bottom-up effect that devastates the ecosystem. The particulate matter released into the atmosphere by volcanic eruptions has a cooling effect on the global climate (by reducing solar radiation) much more so than any warming effect produced by the release of CO_2.
   - The last mass extinction occurred about 65 million years ago (mya), at the boundary of the Cretaceous and Tertiary geologic periods (the K-T boundary). It may have been caused by an asteroid impact or a volcanic eruption. About 75% of all species became extinct, including the (non-bird) dinosaurs.
   - A mass extinction occurred about 200 mya at the boundary of the Triassic and Jurassic geologic periods. It may have been caused by an asteroid impact or a volcanic eruption. About 50% of all species became extinct. The extinction opened up ecological niches that were filled by dinosaurs as they became the dominant terrestrial fauna.
3. **Plate tectonics** (continental drift) describes the movement of land masses, called plates, over the surface of the earth. Fault lines are plate boundaries. When plates collide, they generate earthquakes, create volcanos, and form mountains. Plates that are moving apart form ocean basins between them. The formation of continents arising from the separation of larger plates is a long-term isolating mechanism for speciation. As mountains and volcanos form and as plates move to new latitudes, environmental conditions change, creating new niches for speciation.
   - Australia, Antarctica, South America, Africa, Madagascar, and India were once joined as parts of a supercontinent called Gondwana (also called Gondwanaland). During their early evolution, mammals on Australia, South America, and Antarctica became isolated from other mammals when these continents separated. These mammals evolved into the marsupial mammals, while mammals on the remaining land masses evolved into the placental mammals.

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 lose water through their leaves (transpiration); animals and plants decompose.
2. **Carbon cycle.** Carbon is required for the building of all organic compounds.
   - *Reservoirs:* Atmosphere (as CO_2), bodies of water (as bicarbonate), fossil fuels (coal, oil, natural gas), peat, durable organic material (cellulose, 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 nitrogen-fixing 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:* Bacteria and animals promote the release of nitrogen from organic and inorganic molecules.
     - **Denitrification:** NO_3^- converted to N_2 by denitrifying bacteria.
     - **Ammonification:** Organic compounds converted to NH_4^+ detritivorous bacteria.
     - Excretion of NH_4^+ (or NH_3), urea, and uric acid by animals.
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 and ocean sediments. (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.

Human Impact on Ecosystems

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. **Global climate change.** The solar radiation that passes through the atmosphere consists mostly of visible light, some shorter wavelength ultraviolet (UV) radiation, and some longer wavelength infrared radiation (heat). Some of this solar radiation is reflected by the atmosphere back into space, while the remainder

passes through the atmosphere and is absorbed by the earth. The earth reemits some of the radiation back into the atmosphere, but as longer-wavelength, infrared radiation. As the infrared radiation passes through the atmosphere on its way out into space, it is absorbed by CO_2 and other gases. These gases, called **greenhouse gases,** are transparent to visible and UV radiation but absorb infrared radiation, reemitting it again as infrared, which, subsequently, is trapped and reemitted again by more greenhouse gases. As a result, the energy content of the atmosphere, and its temperature, increase. Because the glass enclosures of a greenhouse also trap heat, the trapping of heat in the atmosphere by energy-absorbing gases is called the **greenhouse effect.** As the food and energy needs of the human population rise, forests are burned for agricultural land and fossil fuels are burned for energy. Burning releases CO_2, and more CO_2 traps more heat. As a result, global temperatures are rising. Warmer temperatures raise sea levels (by melting more ice), decrease agriculture output (by affecting weather patterns), increase human disease (by broadening the range of tropical disease vectors), and threaten extinction to species (by disrupting the environmental conditions to which species are adapted).

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. Although their manufacture has been phased out, CFCs were historically 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,** have appeared over Antarctica, the Arctic, and northern Eurasia, but the ozone layer is predicted to return to normal by 2050 as a result of global cooperation to stop the use of CFCs.
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 acidify soils and bodies of water, decreasing pH and adversely affecting 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 detritivorous 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 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, food, or industrial products.

Review Questions

Multiple-Choice Questions

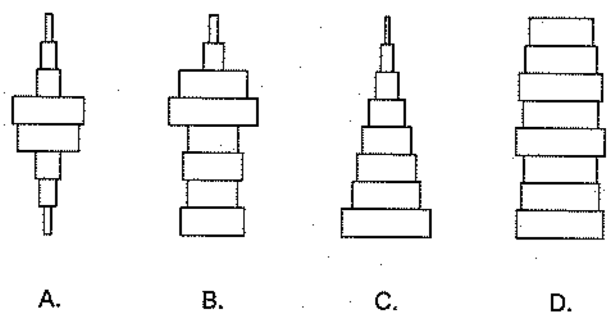
The questions that follow provide a review of the material presented in this chapter. Use them to evaluate how well you understand the terms, concepts, and processes presented. Actual AP multiple-choice questions are often more general, covering a broad range of concepts, and often more lengthy. For multiple-choice questions typical of the exam, take the two practice exams in this book.

Directions: Each of the following questions or statements is followed by four possible answers or sentence completions. Choose the one best answer or sentence completion.

1. A group of interbreeding individuals occupying the same area is best called

A. a community
B. a population
C. an ecosystem
D. a symbiotic relationship

Questions 2–4 refer to the following age structure diagrams that represent four different populations.



2. Which of the above populations is experiencing the fastest growth?

3. Which of the above populations is most nearly experiencing zero population growth over the time period represented by the diagram?

4. Which of the above populations is experiencing the effect of severe limiting factors?

5. All of the following populations would likely result in a uniform dispersion pattern EXCEPT:

A. nesting penguins on a small beach
B. perennial shrubs (of a given species) growing in a desert habitat
C. tropical trees (of a given species) in a tropical rain forest
D. lions on the savanna

Questions 6–7 refer to a population of 500 that experiences 55 births and 5 deaths during a one-year period.

6. What is the reproductive rate for the population during the one-year period?

A. 0.01/year
B. 0.05/year
C. 0.1/year
D. 50/year

7. If the population maintains the current growth pattern, a plot of its growth would resemble

A. exponential growth
B. fluctuating growth
C. *K*-selected growth
D. logistic growth

Use the following key for questions 8–12. Each answer in the key may be used once, more than once, or not at all.

A. commensalism
B. mutualism
C. Batesian mimicry
D. Müllerian mimicry

8. Burr-bearing seeds that are dispersed by clinging to the fur of certain mammals do not harm or help the mammals.

9. The monarch and viceroy butterflies both have orange wings with the same distinctive black markings. When the monarch caterpillar feeds on milkweed, a toxic plant, it stores the toxins, making both the monarch caterpillar and butterfly unpalatable and toxic. The viceroy caterpillar feeds on nontoxic plants, but because viceroy butterflies look like monarch butterflies, predators avoid eating them.

10. Oxpeckers are birds that ride rhinoceroses and other ungulates and eat various skin parasites, such as ticks.

11. Several species of poisonous snakes bear bright colors of red, black, and yellow.

12. Several species of brightly colored, harmless snakes look like poisonous coral snakes.

13. All of the following kinds of plants or animals characterize the initial stages of succession EXCEPT:

A. *r*-selected species
B. species with good dispersal ability
C. species that can tolerate poor growing conditions
D. species that invest large amounts of resources or time into development of progeny

14. Primary succession would occur

A. in a meadow destroyed by flood
B. in a meadow destroyed by overgrazing
C. on a newly created volcanic island
D. in a section of a forest destroyed by an avalanche

15. All of the following increase the concentration of CO_2 in the atmosphere EXCEPT:

A. photosynthesis
B. slash-and-burn clearing of tropical rain forests
C. burning of fossil fuels
D. burning of wood for cooking and heating

16. Nitrogen becomes available to plants by all of the following processes EXCEPT:

A. ammonification
B. denitrification by denitrifying bacteria
C. nitrification by nitrifying bacteria
D. nitrogen fixation in plant nodules

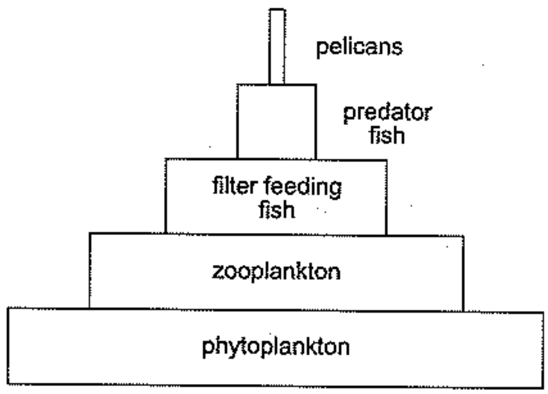
Question 17 refers to the following food chain.

diatoms → oysters → humans

17. In the above food chain, oysters represent

A. detritivores
B. herbivores
C. primary carnivores
D. secondary consumers

Question 18 refers to the following pyramid of biomass.



18. In which trophic level would the biological magnification of the pesticide DDT be most evident?

A. phytoplankton
B. filter feeding fish
C. predator fish
D. pelicans

Question 19 refers to the following table showing the population sizes for a community of three species.

Species	Number of Individuals
Species 1	500
Species 2	400
Species 3	100

19. Calculate Simpson's Diversity Index, D, for the data in the table above using $D = 1 - \Sigma\left(\frac{n}{N}\right)^2$, where n = the number of individuals in a species population and N = the total number of all individuals among all species.

A. 0.42
B. 0.49
C. 0.51
D. 0.58

Free-Response Questions

The AP exam has long and short free-response questions. The long questions have considerable descriptive information that may include tables, graphs, or figures. The short questions are brief but may also include figures. Both kinds of questions have four parts and generally require that you bring together concepts from multiple areas of biology.

The questions that follow are designed to further your understanding of the concepts presented in this chapter. Unlike the free-response questions on the exam, they are narrowly focused on the material in this chapter. For free-response questions typical of the exam, take the two practice exams in this book.

Directions: The best way to prepare for the AP exam is to write out your answers as if you were taking the exam. Use complete sentences for all your answers and do not use outline form or bullets. You may use diagrams to supplement your answers, but be sure to describe the importance or relevance of your diagrams.

1. A species of fly that does not bite or sting has alternating yellow and black stripes on its body. Explain the value these markings bring to these harmless flies.
2. A keystone species has a strong influence on the health of a community. Are you more likely to find a keystone species in a large, complex community or in a small, simple community? Explain your answer.
3. Describe how limiting factors regulate the growth of populations.
4. a. Describe the process of succession for a lake as it develops into a forest.
   b. Compare and contrast the succession of a lake and the eutrophication of a lake polluted by fertilizer or sewage.
5. Explain how two closely related species can occupy the same habitat, seemingly competing for the same kinds of resources.
6. Describe the cycling of nitrogen in an ecosystem.

Answers and Explanations

Multiple-Choice Questions

1. **B.** Since the individuals are interbreeding, they belong to a single species. A group of individuals of the same species is a population.
2. **C.** An age structure diagram that is pyramid-shaped with a broad base represents a population with fast growth.
3. **D.** An age structure diagram with all tiers of approximately the same width represents a population with a constant size.
4. **A.** This age structure diagram indicates high mortality rates among the older and younger generations, an indication that the weakest individuals are experiencing severe density-dependent limiting factors.
5. **D.** Lions are social animals and group in prides (or in bands of bachelor males). In contrast, the remaining answer choices are animals that are likely to be distributed in a uniform pattern, with each individual spaced equally from others. Whenever a population is subject to a limiting resource, there is likely to be competition. In order to minimize conflict, the result of competition is often to distribute the resource equally among all individuals in a population. By equally apportioning space, the penguins minimize conflict. The desert shrubs minimize competition for water. Tropical trees of a single species are also uniformly spaced through the forest, not because of competition, but probably because it minimizes the effect of herbivory and the transmission of parasites and disease. The greater the distance between trees, the more difficulty herbivores have in locating a tree.

6. C. The rate of growth, r, equals $\frac{55 \text{ births} - 5 \text{ deaths}}{500 \text{ per year}}$, or 0.1/year.

7. A. If the reproductive rate is greater than zero ($r > 0$), then the population is growing exponentially.

8. A. This is an example of commensalism because the seeds are helped (dispersal occurs) and the mammals are not harmed or helped by the seeds.

9. C. This is an example of Batesian mimicry because the defenseless viceroy butterfly benefits by mimicking the aposematic monarch butterfly.

10. B. Mutualism occurs when both organisms in the symbiosis benefit. In this example, the oxpeckers obtain food and the rhinos have parasites removed.

11. D. Snakes are Müllerian mimics when they both look alike and possess some kind of aposematic defense (poisonous or unpalatable, for example).

12. C. The brightly colored, harmless snakes are Batesian mimics because they benefit from the defense mechanism of the colorful poisonous snakes they resemble.

13. D. Species that make large parental investments in their offspring—such as oak trees, whose acorns require two years to mature, or mammals that nurse their young—are *K*-selected species and are characteristic of the later stages of succession.

14. C. Because a newly created volcanic island has a pristine substrate (fresh lava), never having been inhabited by living things, it is an example of primary succession. All of the other answer choices would initiate secondary succession.

15. A. Photosynthesis removes CO_2 from the atmosphere. On the other hand, respiration adds CO_2 to the atmosphere, as does the burning of any organic fuel such as wood, coal, oil, natural gas, and gasoline.

16. B. Depending on soil conditions and plant species, plants absorb nitrogen either in the form of NH_4^+ or NO_3^-. Denitrifying by soil bacteria converts NO_3^- to gaseous N_2, a form of nitrogen that plants cannot use. The other answer choices describe processes that generate either NH_4^+ or NO_3^-.

17. B. The beginning of a food chain must begin with producers, in this example, the diatoms. Since the oysters are eating the producers, the oysters are the herbivores.

18. D. DDT concentrates in the pelicans because they occupy the top of the food chain. Because the pesticide results in fragile eggshells that break before incubation is completed, many pelican populations had approached extinction before DDT was banned in the United States.

19. D. To determine the diversity index, calculate $\frac{n}{N}$ for each species, and then square each one. Add together the squares for species 1, 2, and 3. Finally, subtract the sum from 1. Values of D vary from 0 to 1, with higher numbers indicating greater diversity.

Species	n	$\frac{n}{N}$	$\left(\frac{n}{N}\right)^2$
Species 1	500	$\frac{500}{1,000} = 0.5$	$0.5^2 = 0.25$
Species 2	400	$\frac{400}{1,000} = 0.4$	$0.4^2 = 0.16$
Species 3	100	$\frac{100}{1,000} = 0.1$	$0.1^2 = 0.01$
Totals	**1,000**		**0.42**

$$\text{Diversity Index} = 1 - \sum\left(\frac{n}{N}\right)^2 = 1 - 0.42 = 0.58$$

Free-Response Questions

1. These flies are Batesian mimics. By looking like similarly colored bees and wasps, they fool predators into thinking that they are armed and dangerous.

2. Keystone species are more likely to be found in small, simple communities. Large, complex communities have many interacting populations, and the removal of one species can more likely be replaced with another species whose niche may be comparable enough to maintain the stability of the community. If a species can be removed without major negative consequences to the community, then it isn't a keystone species.

3. *For this question, you should begin by describing intrinsic, exponential population growth. Describe how populations experiencing rapid growth can deplete their resources and subsequently crash to extinction. Then, describe the different kinds of limiting factors (density-dependent and density-independent) that restrict populations to logistic growth and that limit the size of populations to the carrying capacity of the habitat. Describe the interaction of predator and prey and why population sizes fluctuate around the carrying capacity. For this question, it is important that you supplement your discussion with graphs of each kind of population growth pattern because they demonstrate your ability to express and interpret data in analytical form.*

4. a. Succession describes the series of communities that occupy an area over time. If the process begins on a newly exposed surface, it is called primary succession. If it occurs on a substrate previously supporting life, such as is the case with most lakes, then it is called secondary succession. Succession occurs because each community changes the habitat in such a way that it becomes more suitable to new species. Soil, light, and other growing conditions change as each community occupies a region. The final, climax community is a stable community that remains unchanged until destroyed by some catastrophic event, such as fire. Then the process begins again.

   The first community to occupy the lake consists of pioneer species with *r*-selected characteristics. These characteristics include good dispersal ability, rapid growth, and rapid reproduction of many offspring. The lake is first populated by algae and protists, followed by rotifers, mollusks, insects, and other arthropods. Various vegetation, such as grasses, sedges, rushes, and cattails, grows at the perimeter of the lake. Submerged vegetation (growing on the lake bottom) is replaced by vegetation that emerges from the surface, perhaps covering the surface with leaves. As the plants and animals die, they add to the organic matter that fills the lake. In addition, sediment is deposited by water from streams that enter the lake. Eventually, the lake becomes marshy as it is overrun by vegetation. When the lake is completely filled, it becomes a meadow, occupied by plants and animals that are adapted to a dry, rather than marshy, habitat. Subsequently, the meadow is invaded by shrubs and trees from the surrounding area. In a temperate mountain habitat, the climax community may be a deciduous forest consisting of oaks or maples. In colder regions, the climax community is often a coniferous forest, consisting of pines, firs, and hemlocks.

   b. Eutrophication is the increase in inorganic nutrients and biomass of a lake. Eutrophication occurs in both unpolluted and polluted lakes. In the natural succession of the lake described above, eutrophication occurred slowly over a period of dozens of years (perhaps over a hundred years). As a result, changes in the chemical and physical nature of the lake allowed for the orderly change of communities, each new community suitable for the new conditions.

   In polluted lakes, eutrophication is accelerated by effluent from sewage or fertilizer. As a result, algae growth occurs rapidly over a period of months. At high densities, algae reduce oxygen levels when they respire at night. When the algae die as shorter winter days approach, rapidly growing aerobic bacteria that feed on the dead algae further deplete the oxygen content of the water. In the absence of oxygen, many of the plants and animals die. The bottom of the lake fills with dead organisms that, in turn, stimulate growth of anaerobic bacteria (some of which produce foul-smelling sulfur gases). In addition, the surface of the lake may become littered with dead fish.

Essay questions about succession are common on the AP exam. You may be asked to describe succession for a particular kind of habitat, as in this question, or you may be given a choice of different kinds of successions. Note that the first paragraph and the beginning of the second paragraph in part a contain very general information that applies to all successional processes. Once you have completed the generalities, describe the successional events for the specific habitat requested. In part b of the question, the first paragraph makes a comparison (states that unpolluted and polluted lakes are both the result of the same eutrophication processes), and the second paragraph makes a contrast (how the rate of eutrophication is faster in a polluted lake).

5. *For this question, you should describe the competitive exclusion principle and how it results in resource partitioning, character displacement, and realized niches.*

6. Although the atmosphere consists of 80% nitrogen gas (N_2), plants can utilize nitrogen only in the form of ammonium (NH_4^+) or nitrate (NO_3^-). Nitrogen fixation, the conversion of N_2 to NH_4^+, occurs by nitrogen-fixing bacteria that live in the soil, or in the root nodules of certain plants such as legumes. In turn, nitrification occurs by certain nitrifying bacteria that convert NH_4^+ to NO_2^- (nitrite) and by other nitrifying bacteria that convert NO_2^- to NO_3^-. In addition, some N_2 is converted to NO_3^- by the action of lightning. On the other hand, denitrification occurs when denitrifying bacteria convert NO_3^- back to N_2.

From the NH_4^+ or NO_3^- absorbed, plants make amino acids and nucleic acids. When animals eat the plants (or other animals), they, in turn, obtain a form of nitrogen that they can metabolize. When animals break down proteins, they produce ammonia (NH_3). Since NH_3 is toxic, many animals, such as aquatic animals, excrete it directly. Other animals convert NH_3 to less toxic forms, such as urea (mammals) or uric acid (insects and birds). When plants and animals die, they decompose through the process of ammonification, in which bacteria convert the amino acids and other nitrogen-containing compounds to NH_4^+, which then becomes available again for plants.

The AP exam may ask you to describe any of the biogeochemical cycles. The nitrogen cycle is the most common request. You may want to supplement your discussion with a drawing using arrows to show the various conversions of nitrogen. If you do make a drawing, however, you must still provide a complete discussion.