Ecosystems

CHAPTER 4

Nature encourages no looseness, pardons no errors.
—Ralph Waldo Emerson

ECOLOGY

Understanding ecosystems requires having an understanding of ecology. Several topics, ranging from communities to niches to biomes, will be discussed.

Biological Populations and Communities

Organisms that resemble each other, that are similar in genetic makeup, chemistry, and behavior, and that are able to interbreed and produce fertile offspring belong to the same species. Organisms of the same species (intraspecific) that interact with each other and occupy a specific area form a population. Populations of different species (interspecific) living and interacting within an area create communities. A community is made up of all the populations of different species that live together within a particular area. An ecosystem is a system formed by the interaction of a community of organisms with their physical environment. Organisms make up populations that make up communities that make up ecosystems that make up the biosphere: biosphere → ecosystems → communities → populations → species → organisms.

Remember

"Intra" means within. "Inter" means between.

Members of a population can be dispersed in an area in three ways:

1. **Clumped.** Some areas within the habitat are dense with organisms, while other areas contain few members.
2. **Random.** Little interaction between members of the population leading to random spacing patterns.
3. **Uniform.** Fairly uniform spacing between individuals.

Ecosystem (Community) Characteristics	
(1) Physical appearance	Relative size; stratification; distribution of populations and species
(2) Species diversity	Number of different species
(3) Species abundance	Number of individuals of each species
(4) Niche structure	Number of ecological niches; how they resemble or differ from each other; species interactions

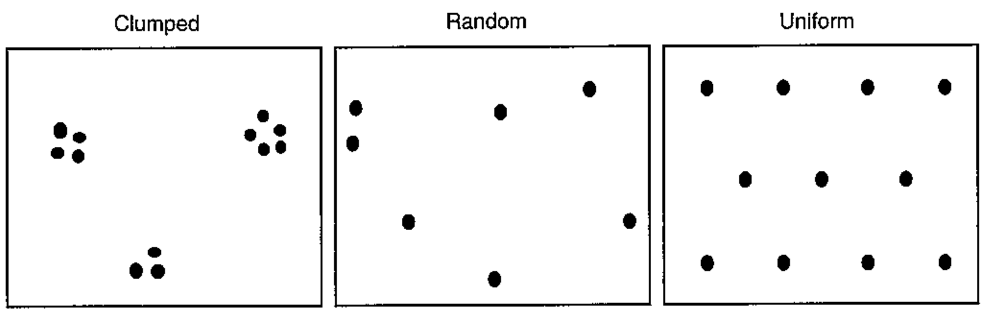

Figure 4.1 Clumped, random, uniform distribution

Ecological Niches

An ecological niche is the particular area within a habitat occupied by an organism and includes the function of that organism within an ecological community. The physical environment influences how organisms affect and are affected by resources and competitors. The niche reflects the specific adaptations that a species has acquired through evolution. To describe an organism's niche involves a description of the organism's adaptive traits, habitat, and place in the food web. A niche also takes into account the types and amounts of resources the species uses and its interactions with both living (biotic) and nonliving (abiotic) factors in its habitat.

Generalist species live in broad niches. They are able to withstand a wide range of environmental conditions. Examples of generalist species include cockroaches, mice, and humans. Specialist species live in narrow niches and are sensitive to environmental changes. Since they cannot tolerate change, they are more prone to extinction. An example of a specialist species is the giant panda, which only eats a certain type of bamboo. When environmental conditions are stable, specialist species have an advantage since there are few competitors as each species occupies its own unique niche (competitive exclusion principle). However, when habitats are subjected to rapid changes, the generalist species usually fare better since they are more adaptable.

Interactions Among Species

Various types of interactions occur among species. They can benefit one or both species, harm one or both species, or not affect one of the species involved.

PRAIRIE DOGS

Prairie dog colonies provide a unique ecological sanctuary for other animals. Where prairie dogs occur, there are greater arthropod and small mammal populations, an increase in bird diversity and density, and greater predator populations. Burrowing owls and reptiles use prairie dog burrows for shelter and hibernation. Prairie dogs are food for many mammalian and avian predators. Approximately 170 vertebrate species are dependent on the prairie dog for survival. Prairie dogs enhance habitat diversity by regulating plant species diversity and by enriching the soil. Burrowing, which aerates and mixes organic material into the soil, alters soil structure and chemistry. The nutrient content of the soil is increased and enhances plant diversity and productivity. Constant grazing near burrows stimulates forb and grass regrowth, and grazed plants have a higher nutritional value than mature plants. Prairie dog grazing and plant regrowth attract livestock, bison, and pronghorn antelope to prairie dog colonies.

Species Diversity

Organisms that live in different environments are specifically adapted to their particular biome.

AQUATIC ORGANISMS

Water provides buoyancy and reduces the need for support structures such as legs and trunks. Water has high thermal capacity, so most aquatic organisms do not spend energy on temperature regulation. Many organisms obtain nutrients directly from the water, thereby reducing energy spent on searching for food. These include filter feeders such as barnacles, clams, and oysters. Water allows dispersal of gametes and larvae to new areas. Water screens out UV radiation. Intertidal organisms have evolved methods of not being swept away by waves and prevent water loss during low tide through shells and exoskeletons, salt-removing mechanisms, and lower metabolic rates due to cooler ambient temperatures.

DESERT ORGANISMS

Desert plants are spaced apart due to limiting factors and consist primarily of succulents (cactus) and short-lived annuals (wildflowers). Succulents store water, have small surface areas exposed to sunlight, have vertical orientation to minimize exposure to the sun, open their stomata at night, have waxy leaves to minimize transpiration, have deep roots to tap groundwater (mesquite and creosote), and have shallow roots to collect water after short rainfalls (prickly pear and saguaro cactus). Sharp spines on cacti reflect sunlight, create shade, and discourage herbivores. Cacti secrete toxins into the soil to prevent interspecific competition (allelopathy). Desert plants store biomass in seeds. Wildflowers have short life spans and are dependent on water for germination.

Desert animals are small and have small surface areas. They spend time in underground burrows where it is cooler, and they are often nocturnal. Aestivation is common. Some animals are able to metabolize dry seeds. Kangaroo rats produce their own water and secrete concentrated urine. Insects and reptiles have thick outer coverings to minimize water loss.

GRASSLAND ORGANISMS

Grasses grow out from the bottom (basal meristem) so they can grow again after being nibbled by grazing animals. Grass species are drought resistant. Deciduous trees and shrubs shed leaves during the dry season to conserve water. Grazers and browsing animals eat vegetation at different heights so as to not compete. Giraffes eat near the top of trees, elephants eat lower down, zebras eat taller grasses, and gazelles eat shorter grasses. Some animals migrate to find water. Others become dormant. Still others survive on seeds during the dry season. Some animals live in burrows to hide and escape predators. In addition, their fur color sometimes matches the color of the surroundings to act as camouflage.

FOREST ORGANISMS

In the tropics, some animals live in tree canopies where shelter and available food supplies (leaves, flowers, and fruits) are abundant and where they can escape from predators that live closer to the ground. Epiphytes (orchids and bromeliads) live on trunks and branches of trees, and they catch organic matter falling from the canopy. Epiphytes do not root in the soil. Instead, they obtain their moisture from the air or from dampness on the surface of their host. Some plants have very large leaves to capture scarce light. Roots of trees are shallow and spread out to capture nutrients in poor soil. To compensate for little support by shallow roots, trees may have buttresses. Flowers have elaborate devices to attract pollinators since wind is minimal in dense growth.

In temperate deciduous forests, broadleaf deciduous trees lose their leaves in winter and become dormant to conserve water and energy. Deciduous trees shift their metabolism from a photosynthesis-based system when light and temperature are favorable to one utilizing glucose and amino acids during the winter. This also helps keep the tree from freezing and acts as a kind of antifreeze.

In evergreen coniferous forests, small, waxy-coated needles are able to withstand the cold and drought of winter and have low surface area to reduce transpiration. Furthermore, conifers are always replacing their needles, unlike deciduous trees that replace their leaves only once a year. Decomposed needles make soil acidic, preventing many competing species from surviving in the soil environment. Some animals hibernate to conserve energy during winter when resources are scarce.

TEMPERATE SCRUB FOREST LAND ORGANISMS

Chaparral plants have small, waxy-coated leaves to reduce transpiration. Many plants produce toxins that leach into the soil to prevent competition (allelopathy). Vegetation becomes dormant during the dry season. Leaves do not fall during the dry season due to the stress of replacing leaves without an adequate water supply. Plant thorns are common for protection. Vegetation is adapted to fires and is common due to the high oil content in the brush. Fires reduce competition and allow seeds to germinate. Rodents are common and store seeds in underground burrows.

TUNDRA ORGANISMS

Polar grassland plants are adapted to low sunlight, low amounts of free water, high winds, and low temperatures. Tundra plants primarily grow during summer months. Leaves on plants have waxy outer coatings. Many plants survive winter as roots, stems, bulbs or tubers. Lichens dehydrate during winter to avoid frost damage.

Animals have adapted in several ways. They have extra layers of fat, chemicals in the blood to keep it from freezing, and compact bodies to conserve heat. They also have thick skin, thick fur, and waterproof feathers above downy insulating feathers.

Interactions Among Species

Interaction	Description
Amensalism 	The interaction between two species whereby one species suffers and the other species is not affected. Usually this occurs when one organism releases a chemical compound that is detrimental to another organism. Examples: The bread mold *Penicillium* secretes penicillin, which is a chemical that kills bacteria. The black walnut tree releases a chemical that kills neighboring plants. Amensalism is common in chaparral and desert communities as it stabilizes the community by reducing competition for scarce nutrients in the water. This chemical interaction is known as allelopathy.
Commensalism 	The interaction between two species whereby one organism benefits and the other species is not affected. Forms of commensalism include: (1) phoresy—using another organism for transportation such as the remora on a shark or mites on dung beetles; (2) inquilinism—using another organism for housing such as epiphytic plants like orchids growing on trees or birds living in the holes of trees; and (3) metabiosis—using something that another organism created such as hermit crabs using the shells of marine snails for protection.
Competition 	Competition can be either intraspecific (competition between members of the same species) or interspecific (competition between members of different species). Competition is the driving force of evolution whether it is for food, mating partners, or territory. Intraspecific competition results in organisms best suited for surviving in a changing environment. Competition is prominent in predator-prey relationships with the predator (seeking food) and the prey (seeking survival). Examples of types of competition include: (1) interference—occurs directly between individuals by interfering with foraging, survival, or reproduction or by preventing a species to establish itself within a habitat; (2) exploitation—occurs indirectly through a common limiting resource that acts as an intermediate; by using the resource it depletes the amount available to others; and (3) apparent—occurs indirectly between two species, which are both sought after by the same predator.
Mutualism 	The interaction between two species whereby both species benefit. Symbiosis is a lifelong positive interaction that involves close physical and/or biochemical contact such as the relationship between trees and mycorrhizal fungi, or the relationships can be shorter as in the case of bees pollinating flowers. Mutualism can be obligatory such as mycorrhizal fungi being totally dependent on their plant hosts, or mutualism can be nonobligatory (facultative) as seen in *Rhizobia* bacteria reproducing either in the soil or in a symbiotic relationship with legumes.
Parasitism 	The interaction between two species whereby one species is benefited at the expense of the other. If the parasite lives on the host, it is known as an ectoparasite (mosquito) and often has elaborate mechanisms and strategies for acquiring a host (leeches that locate their host by sensing movement and confirming the identity through skin temperature and chemical cues before attaching). If the parasite lives within the host, it is known as an endoparasite (tapeworm) and acquires its hosts by passive mechanisms such as the ingestion of egg cells. Epiparasites feed on other parasites. Biotrophic parasites must keep their hosts alive and represent a successful mode of life; many viruses are examples of biotrophic parasites because they use the host's genetic and cellular processes to multiply. Necrotrophs are parasites that eventually kill their hosts. Social parasites involve behaviors that benefit the parasite and harm the host (e.g., cuckoo birds that use other birds to raise their young or the nectar-robbing behavior of insects and birds). Hosts have evolved defense mechanisms (immune systems, plant toxins) to diminish parasitism.

Interactions Among Species (continued)

Interaction	Description
Predation 	Predators hunt and kill prey through the act of predation. Whereas predators kill their prey, parasites have evolved mechanisms to keep their host alive, since their survival depends on a viable host. Predators can be opportunistic and kill and eat almost anything, or they may be specialists and only prey upon certain organisms. Predators that eat only meat are called carnivores; those that eat both meat and vegetation are known as omnivores.
Saprotrophism 	Saprotrophs obtain their nutrients from dead or decaying plants or animals through absorption of soluble organic compounds. Saprotrophs include many fungi, bacteria, and protozoa. Vultures and dung beetles are also saprotrophs.

Keystone Species

A keystone species is a species whose very presence contributes to a diversity of life and whose extinction would lead to the extinction of other forms of life. Through various interactions, a small number of individuals from a keystone species have a very large and disproportionate impact on how ecosystems function. An ecosystem may experience a dramatic shift if a keystone species is removed even though that keystone species was a small part of the ecosystem as measured by biomass or productivity. A classic keystone species is a small predator that prevents a particular herbivorous species from decimating a dominant plant species. Since the prey numbers are low, the keystone predator numbers could be even lower and still be effective. Yet without the predators, the herbivorous prey would explode in numbers, wipe out the dominant plants, and dramatically alter the character of the ecosystem. Specific examples of keystone species are listed below:

GRIZZLY BEAR

Grizzly bears serve as ecosystem engineers by transferring nutrients from oceanic to forest ecosystems. They do this by first capturing salmon from rivers and streams and then by transporting them onto dry land, where the bears leave nutrient-rich feces and partially eaten carcasses.

SEA STARS

Sea stars prey on sea urchins, mussels, and other shellfish that have no other natural predators. If sea stars are removed from the ecosystem, mussel populations explode and drive out other species. Sea urchin populations rise to the point where they begin to decimate coral reefs

SEA OTTERS IN KELP FORESTS

Sea otters prey on sea urchins. Kelp roots serve as anchors and not as nutrient-absorbing systems as found in land plants. If left unchecked, the sea urchins destroy the kelp forests by foraging on kelp roots.

Additionally, animals either migrate during the coldest months or live underground (lemmings).

Edge Effects

An edge effect refers to how the local environment changes along some type of boundary or edge. Forest edges are created when trees are harvested, particularly when they are clear-cut. Tree canopies provide the ground below with shade and maintain a cooler, moister environment below. In contrast, a clear-cut allows sunlight to reach the ground, making the ground warmer and drier—environments not suitable for many forest plants. As time passes and a stand of young trees emerges on a clear-cut, the environment in the young stand changes and the edge begins to fade. As the mature forest develops, the edge fades away.

The edge effect is the result of two different conditions influencing the plants and animals that live on the edge. Some animal species (deer, elk, white-tailed deer, and pheasants) survive well in a forest edge since they are able to find food in the clearing, are able to benefit due to various habitats near one another, are able to hide in the nearby trees, or are well-adapted to human disturbances. These animals are called "edge species." Other animals, such as the spotted owl, do not do well in edges. Negative edge effects become most extreme when forest lands share the edge with agriculture or suburbs. Species composition and diversity can change dramatically if organisms adapted to one set of conditions cannot adapt to the change. If the edge effect is gradual or has indistinct boundaries and over which many species cross, it is called an open community. A community that is sharply divided from its neighbors is called a closed community. Preservation of large blocks of habitat and linking smaller habitat blocks together with migration corridors are techniques to protect rare and endangered species.

Major Terrestrial and Aquatic Biomes

Biomes are a major regional or global biotic community characterized by the dominant forms of plant life and the prevailing climate. Temperature and precipitation are the most important determinants of biomes. Biomes are classified by the type of dominant plant and animal life. Species diversity within a biome is directly related to net productivity, availability of moisture, and temperature.

Biomes

ANTARCTIC

Area surrounding south pole. Rainfall <2 inches (5 cm) per year.

BENTHOS (HADAL)

Bottom of oceans. No sunlight, therefore no plant life. Primary input of energy comes from dead organic matter settling and chemosynthesis.

COASTAL ZONES

Includes estuaries, wetlands, and coral reefs. High diversity and counts of animal and plant species due to runoff from land.

CORAL REEFS

Warm, clear, shallow ocean habitats near land and generally in the tropics. There are three types of coral reefs. Fringing reefs grow on continental shelves near the coastline. Barrier reefs are parallel to shoreline but farther from shore. Coral atolls are rings of coral that grow on top of sunken oceanic volcanoes. Coral reefs are disappearing at an alarming rate due to increase in sea temperature, pollution, dredging, and sedimentation.

DESERTS

Occur between 15° and 25° north and south latitude and generally occur in the interior of continents. Occupy about 20% of all landmass. Rainfall less than 20 inches (50 cm) per year. Air currents are descending, which generally diminishes the formation of rain (rain requires ascending air—orographic lifting). Soils often have abundant nutrients but lack organic matter and consist of sand and closely packed boulders. Little humus in the soil profile.

FRESHWATER WETLANDS

Freshwater wetlands include freshwater swamps, marshes, bogs, prairie potholes (important stopping grounds for migrating birds), ponds, peat bogs, and riparian areas (areas near rivers and streams). Ground is saturated with freestanding water, although standing water can be seasonal. Soil is low in oxygen. Important breeding areas rich in insects, amphibians, and reptiles. Prime areas for human development and recreation resulting in large amounts of habitat destruction. Critical for freshwater supplies. Easily polluted. Dominant plants are floating plants (phytoplankton). Animal life is abundant. Estuaries are rich in nutrients and are breeding grounds for fish. Water input includes runoff, groundwater flow, and streams. A lake is a body of water of considerable size surrounded by land. The vast majority of lakes on Earth are freshwater and most, like in the Northern Hemisphere, are at higher altitudes. Lakes can be classified on the basis of their richness of nutrients, which affects plant growth and animal diversity. Oligotrophic lakes are clear and low in nutrients, which results in a small amount of plant life and other forms of biomass. Eutrophic lakes are rich in nitrogen and phosphorus with large and diverse populations of phyto- and zooplankton, which supports a large diversity of fish. During warm weather, the oxygen content of the water may decrease resulting in die-offs. Hypertrophic lakes are excessively enriched with nutrients and subject to algal blooms. These lakes result from human activity such as the heavy use of fertilizers in the lake catchment area.

GRASSLANDS

Found in areas too dry for forests and too wet for deserts. Rainfall is seasonal. Temperatures are moderate. Grasslands occupy approximately 25% of all land area. Few trees and shrubs due to frequent seasonal fires and water availability. Dominant plants are grasses and perennials with extensively developed roots. Soils are rich in organic matter. Upper soil horizons are alkaline, dark, and rich in humus. Extensively used by humans for agriculture.

HYDROTHERMAL VENTS

Occur in the deep ocean where hot-water vents rich in sulfur compounds are found and that provide energy for chemosynthetic bacteria.

ENERGY FLOW

The ultimate source of energy is the sun. Plants are able to use this light energy to create food. The energy in food molecules flows to animals through food webs.

Photosynthesis and Cellular Respiration

$$6CO_2 + 6H_2O + \text{sunlight} \rightarrow C_6H_{12}O_6 + 6O_2$$

Plants remove carbon dioxide from the atmosphere by a chemical process called photosynthesis, which uses light energy to produce carbohydrates and other organic compounds. Plants capture light primarily through the green pigment chlorophyll. Chlorophyll is contained in organelles called chloroplasts. The glucose or the energy derived from its oxidation during cellular respiration is then used to form other organic compounds such as cellulose (for support), lipids (waxes and oils), and amino acids and then proteins. Oxygen gas is released into the atmosphere during photosynthesis. Plants also emit carbon dioxide during respiration. They produce less carbon dioxide than they absorb and therefore become net sinks of carbon.

Organisms that undergo photosynthesis are called photoautotrophs. Factors that affect the rate of photosynthesis are the amount of light and its wavelength, carbon dioxide concentration, the availability of water, and temperature.

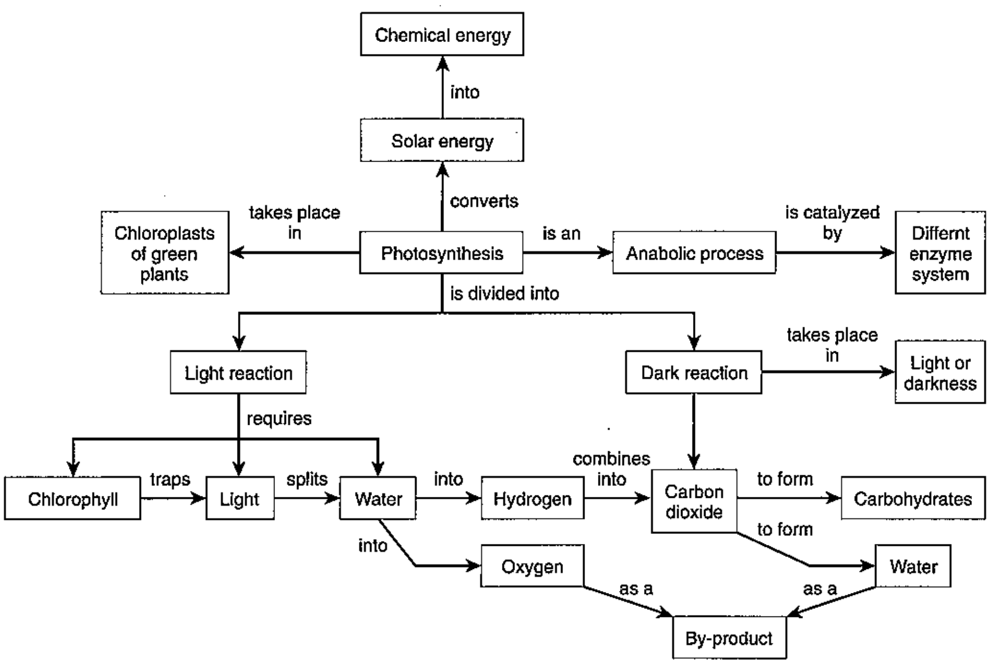

Figure 4.3 Pathways of photosynthesis

Organisms dependent on photosynthetic organisms (autotrophs) are called heterotrophs. In general, cellular respiration is the opposite of photosynthesis. In respiration, glucose is oxidized by the cells to produce carbon dioxide, water and chemical energy. This energy is stored in the molecule adenosine triphosphate (ATP).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

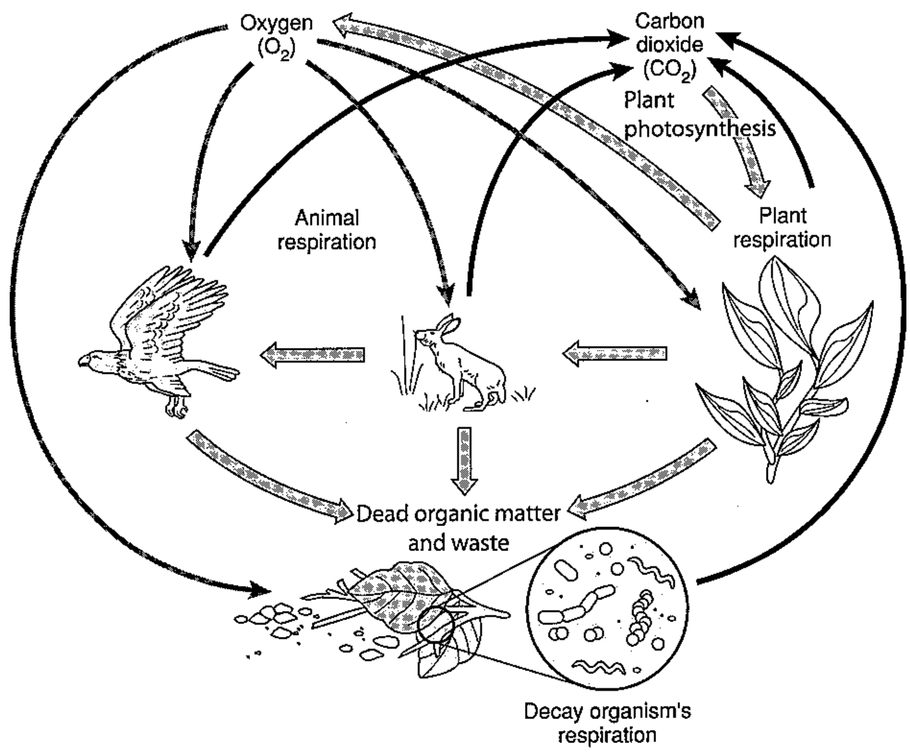

Figure 4.4 The carbon cycle viewed as an ecosystem cycle

Food Webs and Trophic Levels

Primary producers (autotrophs) are plants. They convert solar energy into chemical energy through photosynthesis. Primary consumers are heterotrophs (herbivores—plant eaters) and get their energy by consuming primary producers. Primary consumers have developed defense mechanisms against predation, some of which include:

1. Speed
2. Flight
3. Quills
4. Tough hides
5. Camouflage
6. Horns and antlers

Secondary (and higher) consumers are also heterotrophs and may be either strictly carnivores (meat eaters) or omnivores (eat both plants and animals).

INTERTIDAL

The area of the shoreline exposed to water during high tide and air during low tide. Water movement brings in nutrients and removes waste products. Extremely rich in biodiversity. Susceptible and sensitive to pollution from land runoff and ocean pollution.

OCEAN

Oceans occupy 75% of Earth's surface. Areas of low diversity and low productivity except near the shoreline. Low in nitrogen and phosphorus, which limits plant growth and the smaller organisms that feed on them. Large animals occur but in low density.

SAVANNAS

Warm year-round. Scattered trees. Environment is intermediate between grassland and forest. Extended dry season followed by a rainy season. Consists of grasslands with stands of deciduous shrubs and trees. Trees and shrubs generally shed leaves during the dry season, which reduces the need for water. Food is limited during the dry season, requiring many animals to migrate. Soils are rich in nutrients. Contain large herds of grazing animals and browsing animals that provide resources for predators.

TAIGA (CONIFEROUS OR BOREAL FORESTS)

Generally found between 45° and 60° north latitude. Occupies approximately 17% of land surface. Forests of cold climates of high latitudes and altitudes. Two types of taiga: open woodland and dense forest. More precipitation than the tundra. Generally precipitation occurs during the summer months due to midlatitude cyclones. Soils are generally poor in nutrients because of large amounts of leaching caused by rainfall. The soils are acidic due to the decomposition of needles (an adaptation to conserve water). Deep layer of litter on the surface, and decomposition is slow because of low temperatures. Dense stands of small trees cause understory to be low in light. Low biodiversity due to harshness of environment. Disturbances include fires, storms, and insect infestations.

TEMPERATE DECIDUOUS FORESTS

Forests found in milder temperatures than boreal forests of the taiga. Rapid decomposition due to mild temperatures and precipitation, which results in a small amount of litter on surface. Because of the mild climate, this biome has been greatly exploited by humans for agriculture, lumber, and urban development. Soil is generally poor in nutrients. Tall deciduous trees. Rich and diverse understory. Low density of large mammals due to shade that prevents much ground vegetation.

TEMPERATE RAIN FORESTS

Moderate temperatures and rainfall exceeding 100 inches (250 cm) per year. Low biodiversity because of limited light, which limits food for herbivores. Major resource for timber.

TEMPERATE SHRUBLAND (CHAPARRAL)

Hot, dry summers with mild, cool, and rainy winters. During summer and spring, a subtropical high-pressure zone exists over the area. Rain falls during the winter due to midlatitude cyclones. Average rainfall is between 15–40 inches (30–75 cm) per year. Characterized by dense shrub growth. Decomposition is slow during dry months. Few large mammals. Erosion is common after fires. Because of climate, this area is being utilized for urbanization. Found in select coastal regions.

TEMPERATE WOODLANDS

Drier climate than deciduous forests. Dominated by small trees. Stands of trees are open, allowing light to reach ground. Fires are common.

TROPICAL RAIN FORESTS

High and constant temperature (average approximately 80°F [27°C]). Rainfall ranges between 75–100 inches (200–250 cm) per year. Found within Hadley cells. High species diversity for both plants and animals (up to 100 different tree species per square kilometer as opposed to three to five in temperate zones). Vegetation is dense. Soils are low in nutrients, and most nutrients are stored in vegetation. Soil is acidic. Decomposition of organic material is very fast due to temperature and moisture. Leaching is high. Abundant insect and animal biodiversity. Humans are clearing tropical rain forests for agriculture and cattle raising through a technique called slash and burn. Due to poor soil nutrient levels, agricultural activity lasts for only a limited time and can be sustained only by applying expensive fertilizer, which causes farmers to destroy even more forest.

TROPICAL SEASONAL FOREST

Occurs in areas of seasonal rainfall (monsoon) that is followed by long, dry season. Warm temperatures year-round. Contains mixture of deciduous and drought-tolerant evergreen trees.

TUNDRA

60° north latitude and above. Influenced by polar cells. Alpine tundra is located in mountainous areas, above the tree line with well-drained soil. Dominant animals include small rodents and insects. Arctic tundra is frozen, treeless plains, low rainfall, and low average temperatures with poor drainage due to the frozen ground. Growing season lasts about 2 months. Soil has few nutrients because of low vegetation and little decomposition. Permafrost is permanently frozen ground and a barrier for roots.

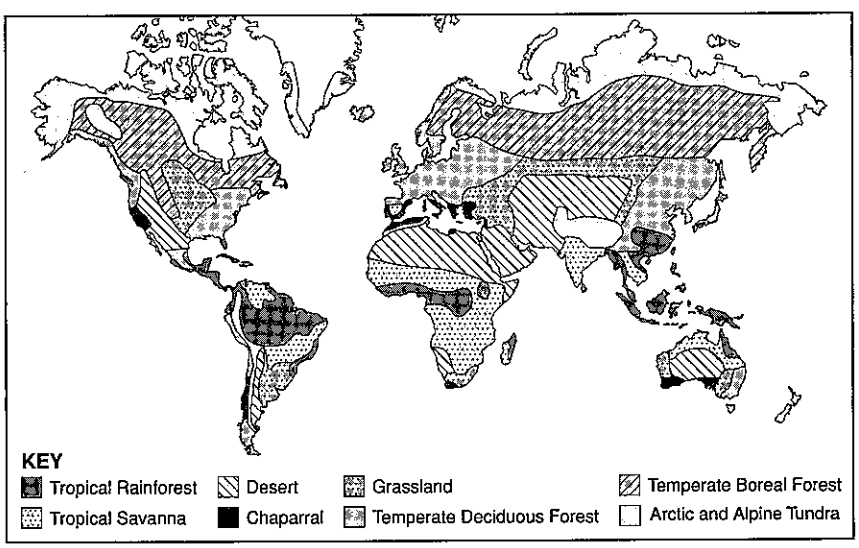

Figure 4.2 Major biomes of the world

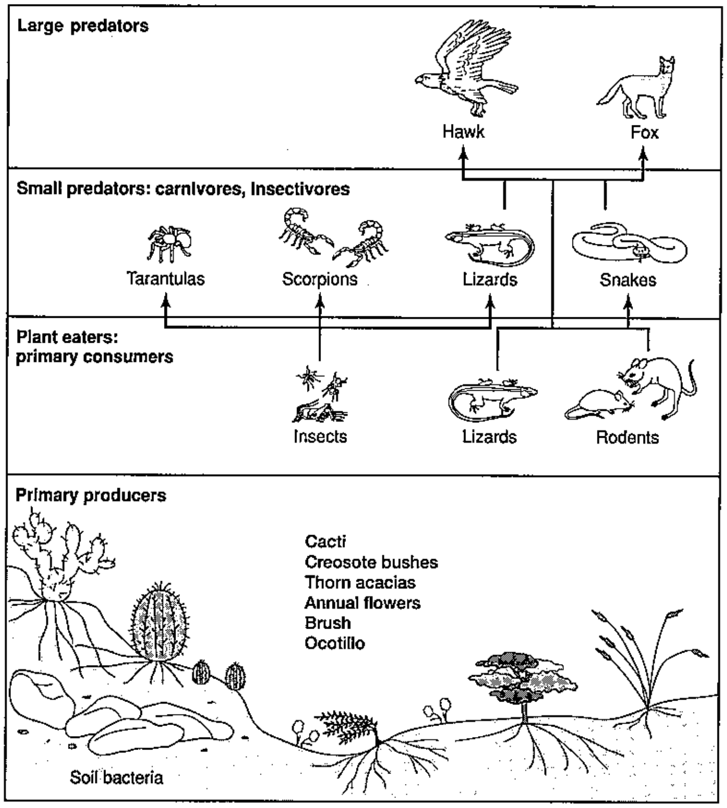

Figure 4.5 Desert food web

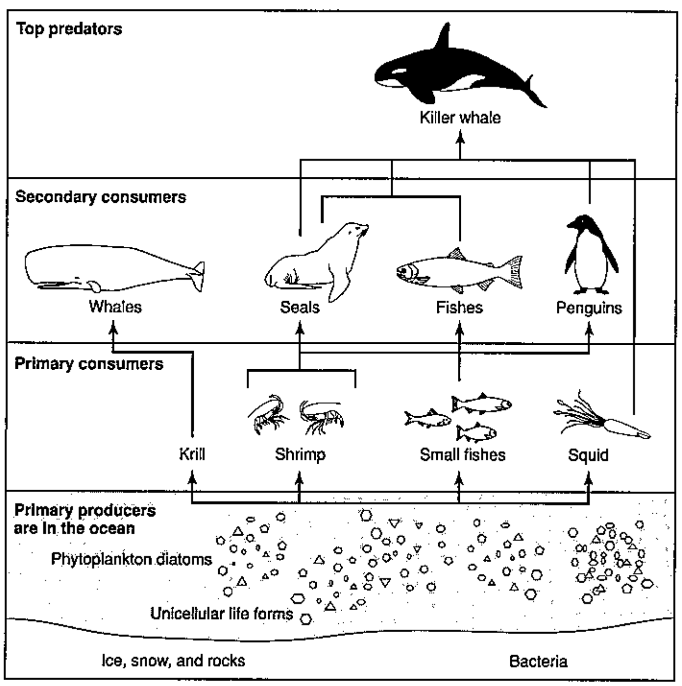

Figure 4.6 Oceanic food web

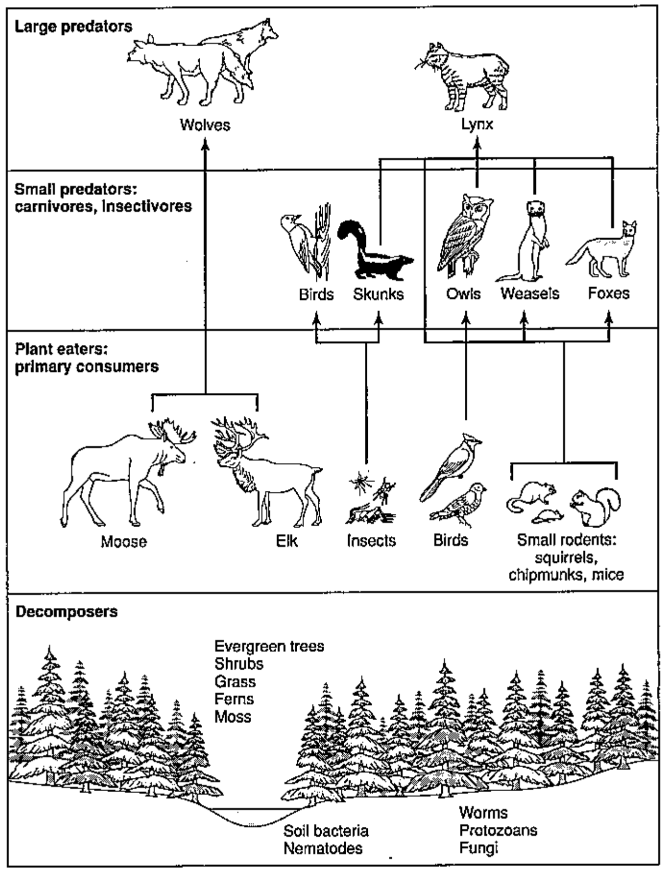

Figure 4.7 Coniferous forest food web

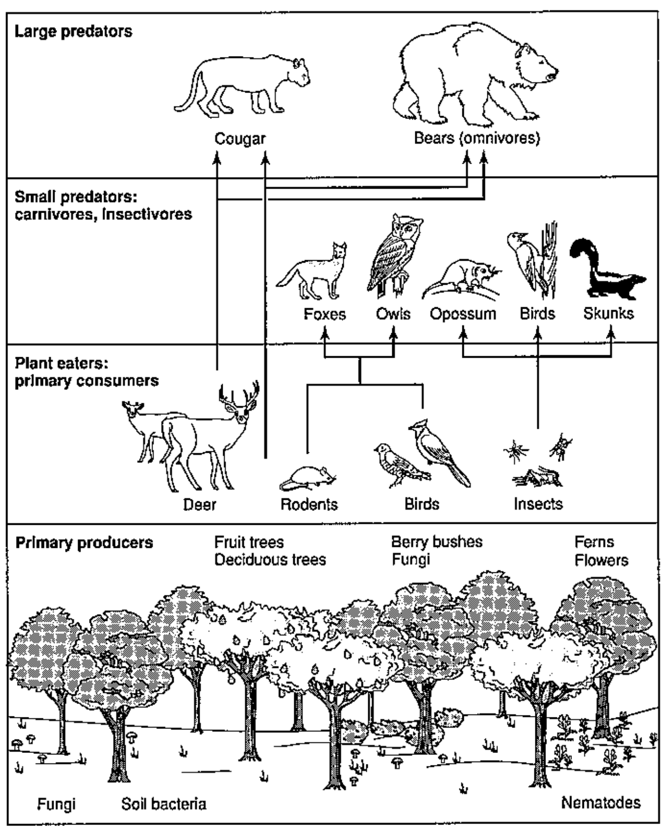

Figure 4.8 Deciduous forest food web

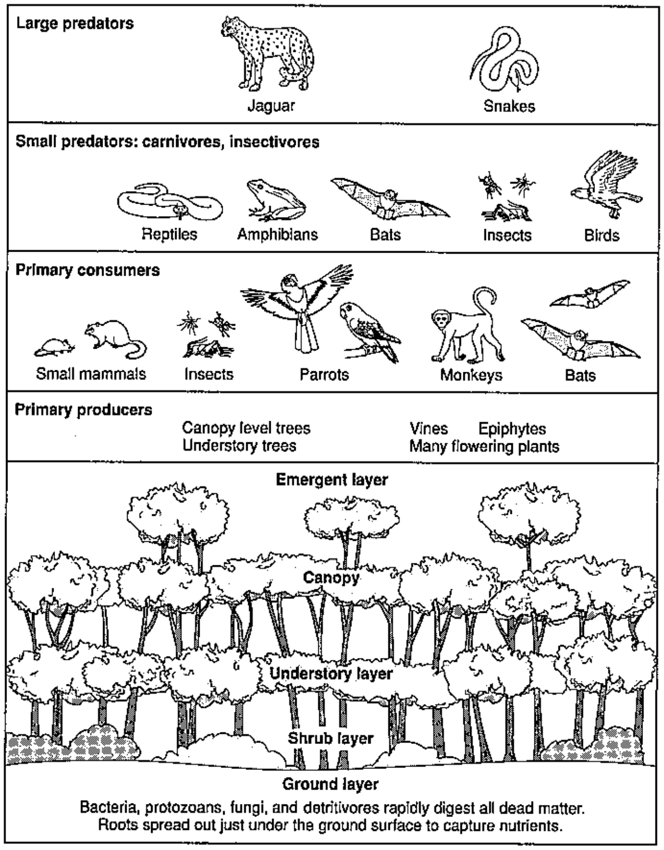

Figure 4.9 Tropical rainforest food web

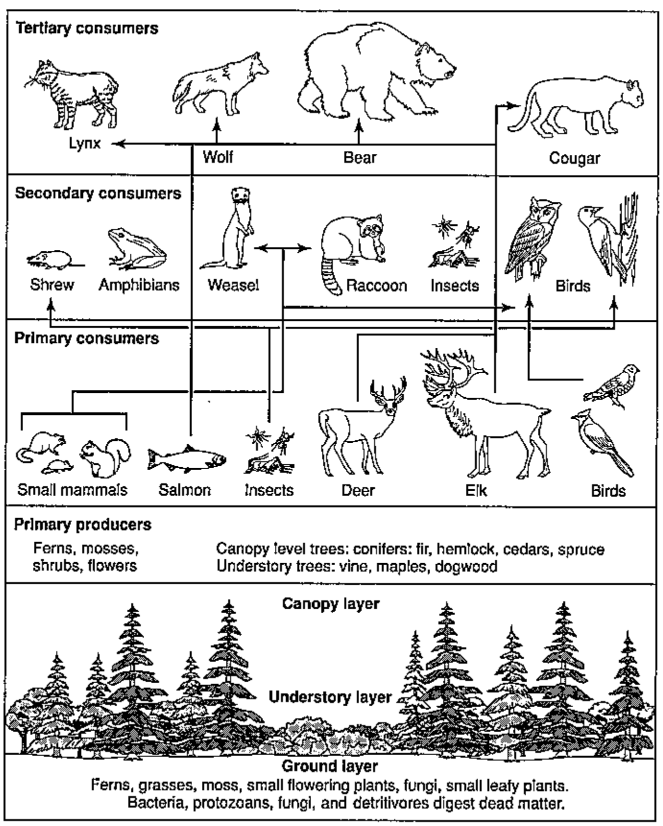

Figure 4.10 Temperate rainforest food web

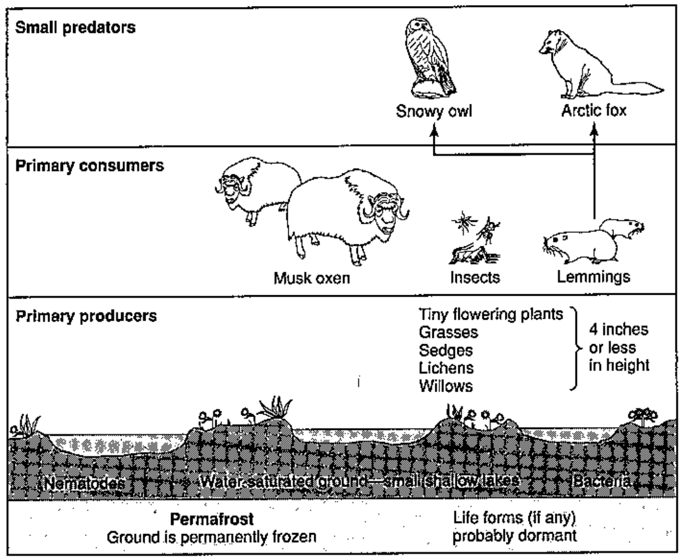

Figure 4.11 Tundra food web

Ecological Pyramids

TIP

As energy flows through systems, more of it becomes unusable at each step.

Sunlight is the ultimate source of energy required for most biological processes (except for chemosynthetic organisms). Less than 3% of all sunlight that reaches Earth is used in photosynthesis. The energy stored in chemical bonds is released to animals and plants through cellular respiration.

Losses of potential energy (in the form of heat energy) occur as one moves up an energy pyramid and conforms with the second law of thermodynamics, which states that any closed system tends spontaneously toward increasing disorder (entropy); some energy is transferred to the surroundings as heat in any energy conversion; and no real process can be 100% efficient. These losses occur in various ways. For example, in digestive inefficiency, much of the plant material is not able to be broken down. For example, elephants need to eat about 5% of their body weight in plant material each day but digest only about 40% of the material that they consume. Other losses occur in energy used by predators for cellular respiration, energy required for temperature regulation, energy used by predators to obtain food or for reproduction, and energy released through the decay of waste products. There is an average 90% loss in available energy as one moves to the next-higher trophic level. Likewise, approximately 10% of the energy entering one level passes to the next.

Detritus energy pyramids (organisms that consume organic wastes) are significantly different in structure. The size of the organisms are smaller, and organisms exist in environments rich in nutrients so energy is not needed to obtain food. Additionally, organisms are generally not able to move on their own to any degree. Finally, trophic levels are more complex and interrelated as they include algae, bacteria, fungi, protozoa, insects, arthropods, and worms.

A notable exception in the scheme of a pyramid of biomass occurs in aquatic ecosystems. In this ecosystem, the producers are mainly microscopic algae. Although the total number of algae is great, their total biomass is quite small at any given time.

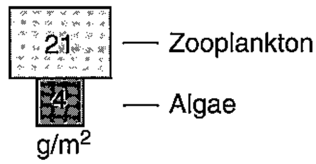

Figure 4.12 Inverted pyramid of biomass—aquatic ecosystem

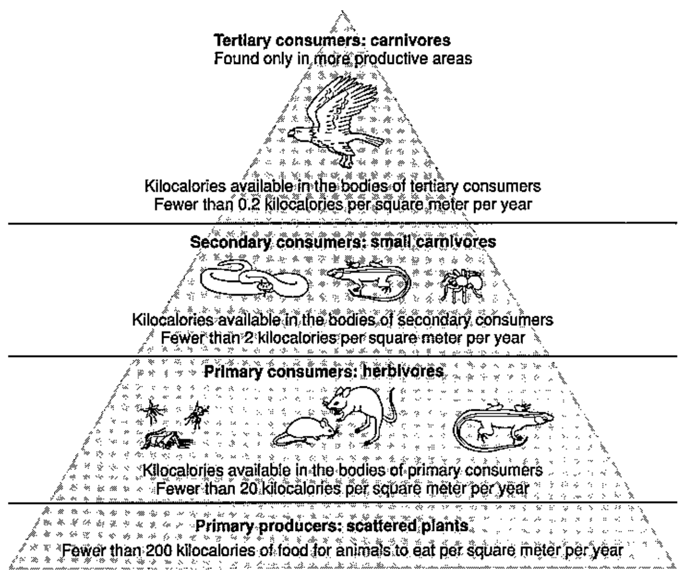

Figure 4.13 Desert biomass—energy pyramid

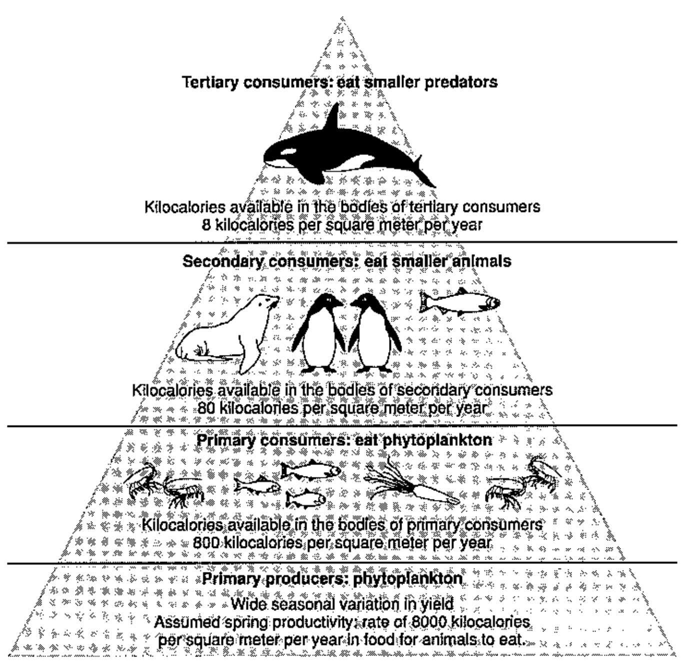

Figure 4.14 Marine biomass—energy pyramid

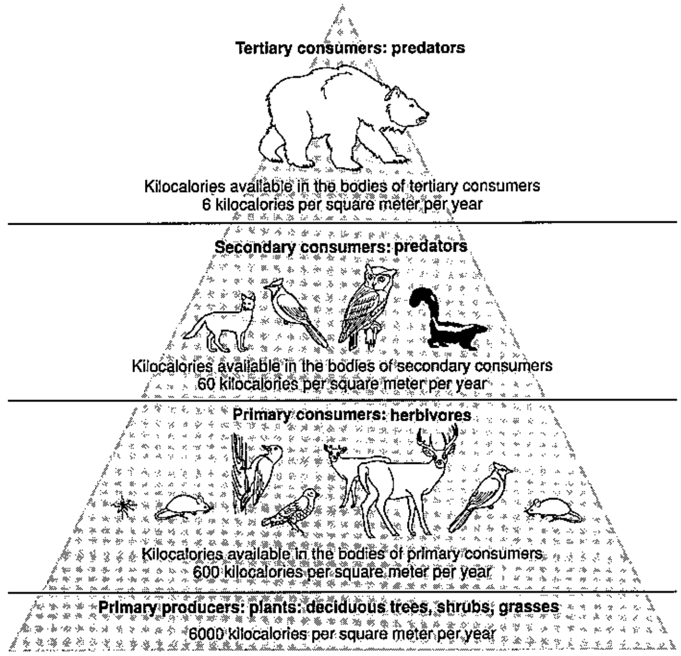

Figure 4.15 Deciduous forest biomass—energy pyramid

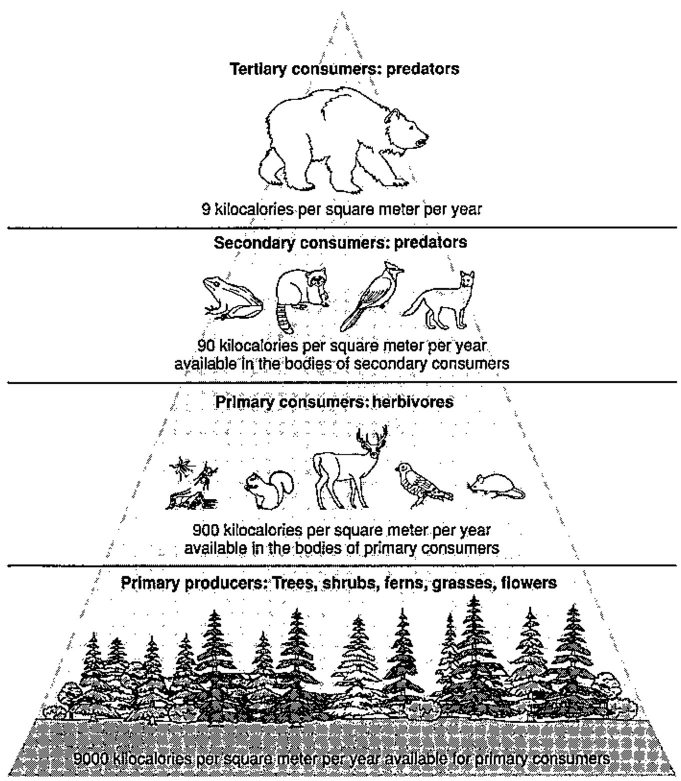

Figure 4.16 Temperate rainforest biomass—energy pyramid

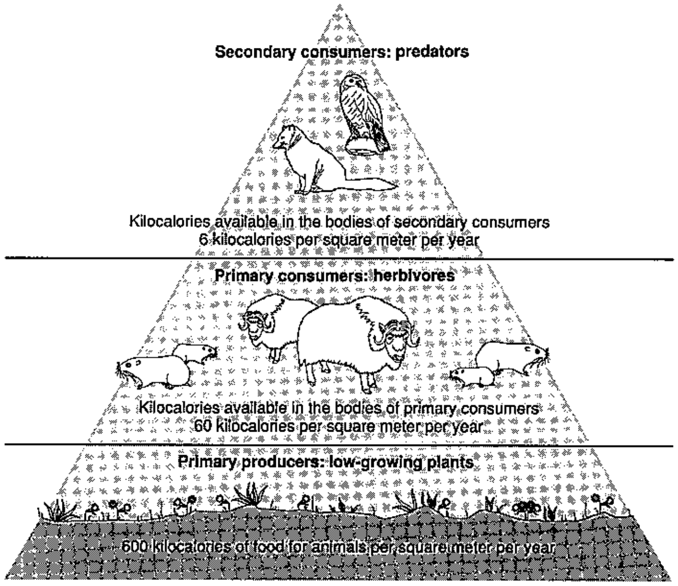

Figure 4.17 Tundra biomass—energy pyramid

ECOSYSTEM DIVERSITY

The topic of ecosystem diversity involves biodiversity, natural selection, evolution, and ecosystem services.

Biodiversity

Biodiversity attempts to describe diversity at three levels: genetic, species, and ecosystem. Genetic diversity involves the range of all genetic traits, both expressed and recessive, that makes up the gene pool for a particular species. Species diversity is the number of different species that inhabit a specific area. For example, tropical rain forests have a higher species diversity than extreme deserts. Ecosystem diversity concerns the range of habitats that can be found in a defined area. Ecosystems are composed of both biotic and abiotic components.

Biodiversity

Diversity Increasers	Diversity Decreasers
Diverse habitats	Environmental stress
Disturbance in the habitat (fires, storms, and so on)	Extreme environments
Environmental conditions with low variation	Extreme limitations in the supply of a fundamental resource
Trophic levels with high diversity	Extreme amounts of disturbance
Middle states of succession	Introduction of species from other areas
Evolution	Geographic isolation

Most scientists believe the total number of species on Earth to be between 10 and 30 million. Tropical rain forests cover approximately 7% of the total dry surface of Earth but hold over half of all of the species. Scientists have given names to only about 1.5 million species.

Natural Selection

Natural selection is the mechanism of how organisms evolve. Natural selection works on the individual level by determining which organisms have adaptations that allow them to survive, reproduce, and be able to pass on those adaptive traits to their offspring. Natural selection occurs over successive generations. Evolution works on the species level by describing how the species attains the genetic adaptations that allow them to survive in a changing environment. Without a changing environment, neither evolution nor natural selection would exist.

The range of genetic variation within a species's gene pool determines whether or not the species, not the individual, has the capacity to adapt and survive to changes in the environment. The expression of that variation in phenotypic and behavioral expressions determines whether the individual survives and is commonly referred to as survival of the fittest. "Fittest" means the ability to reproduce and pass on genes to offspring. New genes enter the gene pool through mutation and when combined with a change in gene frequency, results in evolution at the species level. Natural selection operates in three ways: stabilizing, directional, and disruptive.

STABILIZING SELECTION

Stabilizing selection affects the extremes of a population and is the most common form of natural selection. The individuals that deviate too far from the average conditions are removed. The results are a decrease in diversity, maintenance of a stable gene pool, and no evolution. For example, human babies that are too low in weight or too high in weight have survival problems.

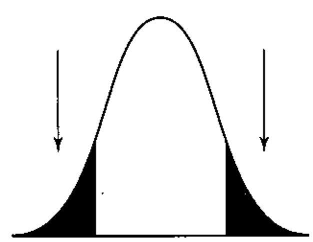

Figure 4.18 Stabilizing selection

DIRECTIONAL SELECTION

Directional selection affects the extremes of a population. Individuals toward one end of the distribution may do especially well, resulting in a frequency distribution toward this advantage in future generations. An example is the industrial melanism of the peppered moth and the evolution of the horse. The early horse present during the early Eocene was a small-bodied creature that moved well through heavy brush and woodlands. Today's horse, with its long legs designed for speed in the open grassland and changes in its dental and toe structure, looks nothing like its ancestor.

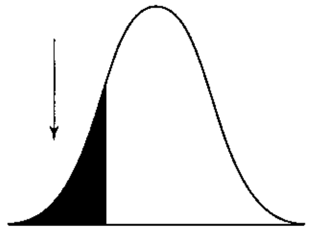

Figure 4.19 Directional selection

DISRUPTIVE SELECTION

Disruptive selection acts against individuals that have the average condition and favors individuals at the extreme ends (bimodal). The population is essentially split into two. Both directional and disruptive selection affects the gene pool. In both cases, the population changes and evolution occurs.

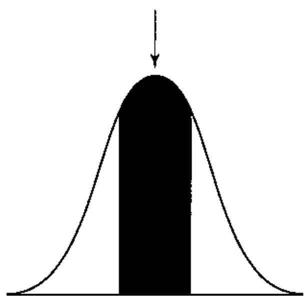

Figure 4.20 Disruptive selection

Natural Selection

Process of Natural Selection	Description
Competition	There is a struggle to survive, and competition exists for limited resources.
Disproportionate increase and persistence in phenotypic adaptation in successive populations	Variations that are advantageous to the individual in terms of survival allow more organisms possessing the trait(s) to survive, reproduce, and pass on the characteristic(s) to future generations.
Geometric (or exponential) increase in population	If all offspring survived, there would be astronomical numbers of individuals.
Individual variations	There is variation in offspring. For natural selection, the variations must be gene expressed and be capable of being inherited.
Limited resources	Earth has finite resources.

More often than not, natural selection is based upon the cumulative effects of numerous genes, each responsible for slight changes. When genes at more than one locus contribute to the same trait, the result is called a polygenic effect.

Polyploidy occurs in plants when the entire set of chromosomes is multiplied. It is an example of sympatric speciation in which species arise within the same, overlapping geographic range. This can occur through the process of hybridization. In hybridization, chromosomes from two different species are artificially combined to form a new species (hybrid). In another type of hybridization, chromosomes naturally fail to segregate during meiosis, producing diploid gametes. If the hybrid has adaptive traits to survive in the new environment, a new species of plant has been produced. Although the plant may not be able to reproduce sexually, it may be able to reproduce through vegetative means. Examples of polyploidy include cotton, tobacco, sugarcane, bananas, potatoes, and wheat. More than half of all known species of plants today (260,000 species) may have originated through polyploidy.

Evolution

Change generally takes a very long time and is supported by the fossil record. Evolution is the change in the genetic composition of a population during successive generations as a result of natural selection acting on the genetic variation among individuals and resulting in the development of new species. The concept of a "common ancestor" states that similarities among species can be traced back through a phylogenetic tree.

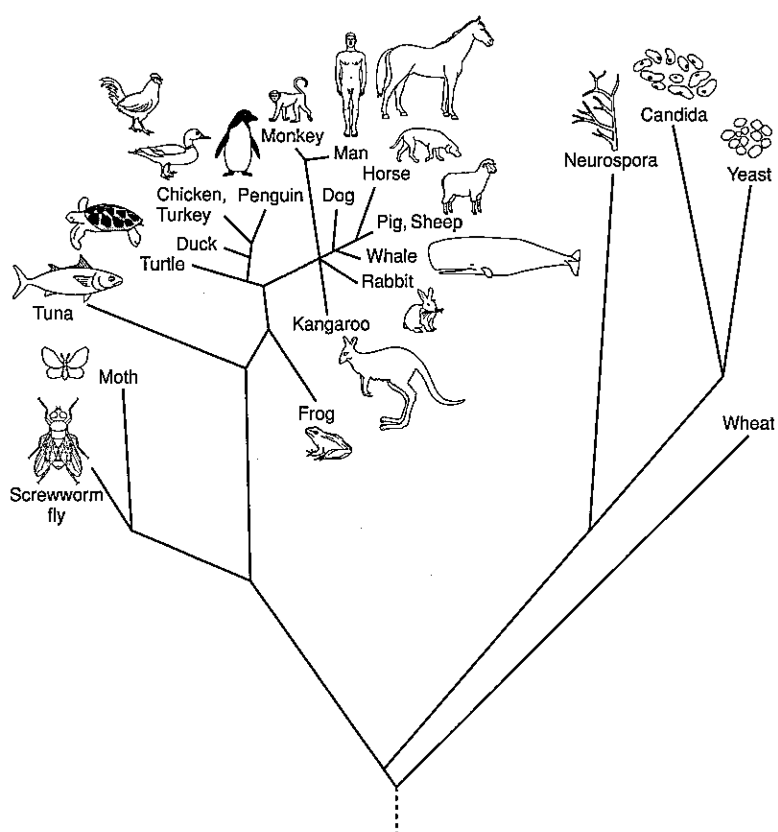

Figure 4.21 Phylogenetic tree traced through analysis of cytochrome C.

SPECIATION

Speciation results when segments of a population of one species become so isolated that gene flow stops. Adaptive radiation describes rapid speciation to fill ecological niches and is driven by either mutation and/or natural selection. Three basic types of adaptive radiation are: general adaptation, environmental change, and geographic isolation. In general adaptation, a species develops a radical new ability to reach new parts of its environment; for example, bird flight. With environmental change, a species that can, in contrast with the other species in the ecosystem, successfully survive in a radically changed environment and branch into new species that covers the new niches. An example is the rapid spread and development of mammalian species after the extinction of the dinosaurs. In geographic isolation, isolated ecosystems, such as archipelagos and mountain areas, can be colonized by a species that upon establishing itself undergoes rapid divergent evolution. A classic example of geographic isolation is the Darwin finches of the Galapagos Islands in which ancestral groups of finches from the mainland of Ecuador were blown to the Galapagos Islands. The isolated groups of finches were subjected to different selective pressures on different islands that, over time, resulted in separate species.

CONVERGENT EVOLUTION

Convergent evolution describes the process whereby organisms not closely related to each other independently acquire similar (analogous) characteristics while evolving in separate and sometimes varying ecosystems. An example of convergent evolution is the development of wings in birds, insects, and bats even though the organisms are not closely related.

EVOLUTIONARY RELAY

Evolutionary relay occurs when independent species acquire similar characteristics through their evolution in similar ecosystems but not at the same time. An example of evolutionary relay is the development of a dorsal fin in both sharks and the prehistoric ichthyosaurs (extinct marine reptiles).

PARALLEL EVOLUTION

Parallel evolution occurs when two independent species evolve together at the same time and in the same ecosystem and acquire similar characteristics. A classic example of parallel evolution is the evolution of the placentals and the marsupials. Placental animals bear their young fully developed. Marsupials give birth prematurely and nurture their young in a pouch. In the plant kingdom, parallel evolution is seen in the similar forms of leaves, where similar patterns have appeared over and over again in separate genera and families.

GRADUALISM AND PUNCTUATED EQUILIBRIUM

Gradualism views evolution as a slow, stepwise development of a species over long periods of time (millions of years). Punctuated equilibrium proposes that some species arose suddenly in a short period of time (thousands of years) after long periods of stability. These bursts of rapid evolution are thought to have been triggered by changes in the physical or biological environment—perhaps a period of drought or the appearance of a new, more challenging predator. A classic example of punctuated equilibrium is the abrupt appearance of flowering plants without a fossil record.

Ecosystem Services

Ecosystem services are the processes by which the environment produces resources. Examples include clean water, timber, habitat for fisheries, and pollination of native and agricultural plants. Ecosystems provide the following services:

- Moderate weather extremes and their impacts
- Disperse seeds
- Mitigate droughts and floods
- Protect people from the sun's harmful ultraviolet rays
- Cycle and move nutrients
- Protect stream and river channels and coastal shores from erosion
- Detoxify and decompose wastes
- Control agricultural pests
- Maintain biodiversity
- Generate and preserve soils and renew their fertility
- Contribute to climate stability
- Purify the air and water
- Regulate disease-carrying organisms
- Pollinate crops and natural vegetation

Species Movements

Many of the different types of organisms that inhabit Earth have the ability to move. This movement can be accomplished either passively or actively. Examples of active movement include walking, running, flying, or swimming. In passive movement, the organism uses some external force to cause transit. For example, plants can use wind for seed dispersal while oyster larvae can passively travel great distances by sea currents.

One common factor of why organisms move is to disperse to new habitats to reduce intraspecific competition. By finding new suitable habitats, individuals can increase the range of their species. A larger range makes the species better off in terms of evolution.

The geographic distributions of plant and animal species are never fixed over time. Geographic ranges of organisms shift, expand, and contract. These changes are the result of two contrasting processes: colonization and establishment, and localized extinction. Colonization and establishment takes place when populations expand into new areas. A number of processes can initiate this process, including disturbance and abiotic environmental change. Localized extinction results in the elimination of populations from all or part of their former range. It can be caused by biotic interactions or abiotic environmental change.

Plants have developed a number of different mechanisms for dispersing their offspring:

1. The use of specialized structures to aid the transport of an individual by wind
2. The employment of particular structures to transport the individual by moving water
3. The production of fruit-encased seeds that other organisms consume and disperse
4. Adhesion mechanisms
5. The physical ejection of seeds

Once dispersed, an individual can colonize a new site only if it is devoid of other organisms and if the necessary abiotic requirements and conditions exist for its survival. Sites within ecosystems become devoid of organisms through disturbance. A disturbance can be caused by predation, climate variations, earthquakes, volcanoes, fire, animal burrowing, and even the impact of a raindrop. Often the struggle for survival does not end with colonization of an individual on a vacant site. Once colonized, an individual may not be able to establish itself over the long term because of abiotic and biotic influences. The death of the individual may occur through competitive interaction, predation or an abiotic factor like fire.

Ecological Succession

Succession is the gradual and orderly process of ecosystem development brought about by changes in community composition and the production of a climax community characteristic of a particular geographic region. It describes the changes in an ecosystem through time and disturbance. Rates of succession are affected by several factors.

- Facilitation is when one species modifies an environment to the extent it meets the needs of another species.
- Inhibition is when one species modifies the environment to an extent that it is not suitable for another species.
- Tolerance is when species are not affected by the presence of other species.

Earlier successional species frequently called pioneer species are generalists. Pioneer plants have short reproductive times (annuals), and pioneer animals have low biomass and fast reproductive rates. Later successional species include larger perennial plants and animals with greater biomass, longer generational times, and higher parental care.

Types of Succession

Type	Description
Allogenic	Changes in the environmental conditions create conditions beneficial to new plant communities.
Primary	The colonization and establishment of pioneer plant species on bare ground. (Example: lichens on bare rocks)
Progressive	Communities become more complex over time by having a higher species diversity and greater biomass.
Retrogressive	The environment deteriorates and results in less biodiversity and less biomass.
Secondary	Begins in an area where the natural community has been disturbed but topsoil remains. (Example: forest fire)

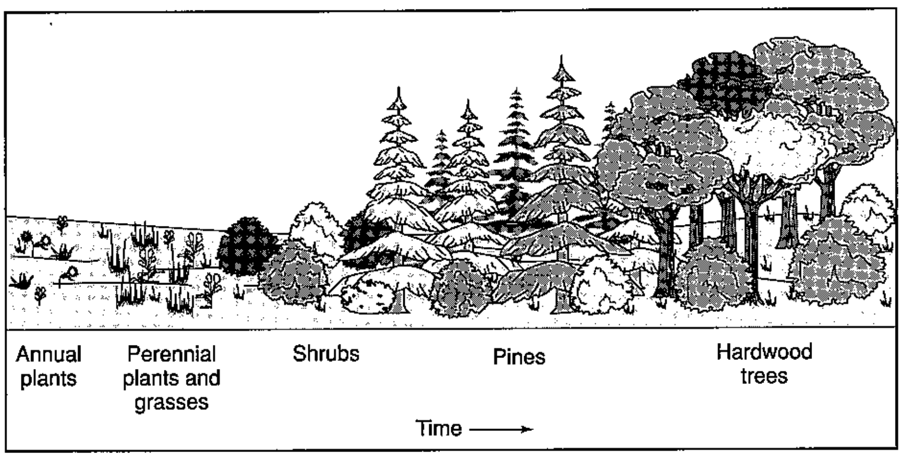

Figure 4.22 Stages of succession in a temperate deciduous forest. The time span from annual plants to hardwood trees is over 100 years

The following table lists the characteristics of succession within plant communities:

Characteristics of Succession-Plant Communities

Characteristic	Early Successional Stage	Late Successional Stage
Biomass	Limited.	High in tropics and wetlands; limited in deserts.
Consumption of soil nutrients	Nutrients are quickly absorbed by simpler plants.	Since biomass is greater and more nutrients are contained within plant structures, nutrient cycling between the plant and soil tends to be slower.
Impact of macroenvironment	Early plants depend primarily on conditions created by macro-environmental changes (fires, floods, etc.).	These plant species appear only after pioneer plant communities have adequately prepared the soil.
Life span of seed	Long. Seeds may become dormant and able to withstand wide environmental fluctuations.	Short. Not able to withstand wide environmental fluctuations.
Life strategy	*r*-strategists: mature rapidly; short-lived species; number of organisms within a species is high; low biodiversity; niche generalists.	*K*-strategists: mature slowly; long-lived; number of organisms within a species is lower; greater biodiversity; niche specialists.
Location of nutrients	In the soil and in leaf litter.	Within the plant and top layers of soil.
Net primary productivity	High.	Low.
Nutrient cycling by decomposers	Limited.	Complex.
Nutrient cycling through biogeochemical cycles	Because nutrient sinks have not fully developed, the nutrients are available to cycle through established biogeochemical cycles fairly rapidly.	Because of nutrient sinks (carbon being trapped in vegetation), nutrients may not be readily available to flow through cycles.
Photosynthesis efficiency	Low.	High.
Plant structure complexity	Simple.	More complex.
Recovery rate of plants from environmental stress	Plants quickly and easily come back.	Recovery is slow.
Seed dispersal	Widespread	Limited in range.
Species diversity	Limited	High.
Stability of ecosystem	Since diversity is limited, ecosystem is subject to instability.	Due to high diversity, ecosystem can withstand stress.

QUICK REVIEW CHECKLIST

- ☐ **Biological Populations and Communities**
  - ☐ ecosystem characteristics
  - ☐ population dispersal patterns
  - ☐ ecological niches—generalists vs. specialists
  - ☐ biological interactions
    - ☐ amensalism
    - ☐ commensalism
    - ☐ competition
    - ☐ mutualism
    - ☐ parasitism
    - ☐ predation
    - ☐ saprotrophism
    - ☐ keystone species (examples)
- ☐ **Species Diversity (Adaptations)**
  - ☐ aquatic organisms
  - ☐ desert organisms
  - ☐ grassland organisms
  - ☐ forest organisms
  - ☐ temperate scrub forest land organisms
  - ☐ tundra organisms
- ☐ **Edge Effects**
- ☐ **Biomes**
  - ☐ Antarctic
  - ☐ benthos
  - ☐ coastal zones
  - ☐ coral reefs
  - ☐ deserts
  - ☐ freshwater wetlands
  - ☐ grasslands
  - ☐ hydrothermal vents
  - ☐ intertidal zones
  - ☐ ocean
  - ☐ savannas
  - ☐ taiga
  - ☐ temperate deciduous forests
  - ☐ temperate rainforests
  - ☐ temperate scrubland (chaparral)
  - ☐ temperate woodlands
  - ☐ tropical rainforests
  - ☐ tropical seasonal forests
  - ☐ tundra
- ☐ **Energy flow**
  - ☐ photosynthesis
  - ☐ cellular respiration