Chapter 2

The Living World

For an ecosystem to function properly and remain healthy, countless organisms and the environment have interactions that affect one another. To understand how an ecosystem functions, it is necessary to understand the living components, how they work together, and how they are affected by other biotic and abiotic factors. This chapter reviews the structure of ecosystems, the relationships between organisms and their environment, energy flow and nutrient cycling, and ecosystem changes.

Ecosystem Structure

Ecosystems are made up of all their living and nonliving components interacting in a specific area at the same time. The parameters of an ecosystem can vary, but all ecosystems are made up of the same components. Every ecosystem contains communities and populations of organisms, which are made up of a variety of species and individual organisms, all interacting with the abiotic factors including rocks, water, and climate. Lifting up a rock in a forest can expose a mini-ecosystem. A forest functions as an ecosystem, while Earth's entire biosphere can also be considered an ecosystem.

Biological Populations and Communities

A group of individuals (organisms) of the same species living in the same area at the same time is considered to be a **population.** For example, all the black bears currently living in eastern Oregon would be a population. A **community** is made up of multiple populations of different species in a given area. As an example, in eastern Oregon, the American badger, bullfrog, painted turtle, deer mouse, elk, mountain lion, black bear, and Douglas squirrel populations are all part of the animal community within this region, along with many other species. Population ecology examines how the individuals within a species interact, while community ecology examines how a variety of species interact. (For additional information on population ecology, refer to Chapter 3.)

Ecosystems are made up of not only the living organisms in an area but the nonliving components as well. When studying populations and communities, the habitats are also important for understanding interactions and ultimately species' survival and reproduction. An organism's **habitat** is the location in which it lives, and it includes the soil, vegetation, water supply, and many other factors.

Within most ecosystem communities are **keystone species,** which are species that have an important and dramatic affect on the ecosystem in which they live. This is not to say that other organisms are not important—a keystone species has an effect on a wide range of other organisms, impacting both the ecosystem's structure and functioning. Examples of keystone species include sea otters, elephants, beavers, and wolves.

Ecological Niches

An organism's **niche** is both how the organism uses its resources and its role in the community. Niche components include habitat use, food consumption, interactions with other species, and shelter, among many other aspects. Organisms that have the ability to survive in a variety of environments and can adjust to different situations and niches are considered to be **generalists.** They can handle changing conditions and temperatures and do not especially thrive in any specific type of environment. **Specialists,** on the other hand, have adapted to a specific environment and are very good at their role within that niche, but this makes the species more vulnerable to any type of change.

Species Interactions

In ecosystems, organisms interact with other organisms in a variety of ways. Interactions can lead to positive or negative effects on the organisms involved. These interactions include competition, mutualism, predation, parasitism, herbivory, commensalism, and amensalism.

Competition is the process by which organisms vie for the same resources, resulting in one outperforming the other. Resources over which competition occurs include food, water, shelter, mates, and sunlight. When two or more different species compete, it is called **interspecific competition.** When individuals of the same species compete, the situation is called **intraspecific competition.** When organisms are in competition, generally each has a negative impact on the other, since one will outcompete the other for the resource. In some situations, though, species adapt to competition over time through evolution. The result is that each species reduces competition with others by sharing a resource but using it differently or by using somewhat different resources to fulfill its needs. This is called **resource partitioning.**

In **mutualistic interactions,** two or more species benefit from one another, each helping the other. For example, bees and flowers help one another. The bees take nectar and pollen from the flowers for food while also assisting with the spreading of pollen from one flower to another. Neither organism is harmed during their interactions. Another example is lichens, which are made up of fungi and algae living together in a symbiotic relationship. The fungi provide shelter for the algae, and the algae provide food for the fungi through their photosynthetic abilities. Lichens are also an important pioneer species.

During **predation,** one species hunts, captures, kills, and consumes another species, resulting in the second species' instant demise. One species benefits and the other is harmed. This is a predator/prey relationship. Because this relationship is how energy is transferred throughout the trophic levels of ecosystems, most predators are also prey at some point. This relationship contributes to the dynamics of a population. The more prey there are, the greater number of predators that can be supported. More prey supports an increase in the number of predators, but at some point the population of predators will meet its carrying capacity and will start to decline. The prey population will eventually begin to increase again once the predators decline, keeping the predator/prey cycle in motion.

With **parasitism,** one organism uses another for food and nutrients while also harming the other individual. The **parasite** is the organism that benefits, and the **host** is the organism that is harmed. The damage usually is not immediate but occurs over a period of time. Parasites can live in a variety of places relative to their hosts. Some live inside their hosts, others live on their exterior, and still others live on their own and meet their hosts only sporadically. Often, parasites and hosts will evolve relative to each other in a process called **co-evolution.**

When plants are consumed by animals, the process is termed **herbivory.** In this interaction, the plants' growth and reproduction are affected, while the animals benefit from the nutrients the plants provide. The most common herbivores are insects. In many cases, plants produce defenses—such as toxins, thorns, or hairs—to discourage herbivorous consumers.

Commensalism is the process by which one species benefits from their relationship and the other species is neither positively nor negatively affected. For example, cattle egrets are often seen around cattle, standing on their backs and on the ground around them. The egrets benefit because the cattle's movements stir up insects on which the birds feed, while the cattle are not affected in either a positive or negative way by the egrets' presence.

In **amensalistic relationships,** one organism harms or inhibits another while remaining unaffected itself. Only limited examples of amensalism are understood because of the difficulty in proving that one species does not in some way benefit from the harm it has caused to another. A common example, though, is the fungus *Penicillium notatum,* which produces the antibiotic penicillin. Penicillin inhibits the growth of certain types of bacteria, but it appears that the *Penicillium* is unaffected.

Summary of Effects of Species Interactions

Interaction	Species A	Species B	Description
Competition	Harmed	Harmed	Organisms vie for the same resource.
Predation	Benefits	Harmed	One organism hunts, captures, kills, and consumes another.
Parasitism	Benefits	Harmed	One organism benefits from another organism while at the same time doing it harm.
Herbivory	Benefits	Harmed	Animals consume plant tissues.

Interaction	Species A	Species B	Description
Mutualism	Benefits	Benefits	Two organisms both benefit from one another.
Commensalism	Benefits	Unaffected	One organism benefits while the other is unaffected.
Amensalism	Unaffected	Harmed	One organism is unaffected while harming another.

Biomes: Terrestrial and Aquatic

Throughout the planet are a variety of **biomes,** large ecological areas dominated by a particular plant type. The location of biomes is based on many factors, including temperature, precipitation, soil type and characteristics, and oceanic and atmospheric circulation. Precipitation and temperature are the main influence on vegetation type and, therefore, on biomes.

Aquatic biomes are slightly more complicated to define and are not grouped the same way as terrestrial biomes. Salinity, temperature, nutrients, currents, depth, wave action, and bottom substrate, as well as animal life, all help to define an aquatic biome. Aquatic biomes include lakes, rivers, streams, ponds, wetlands (freshwater and marine), estuaries, and coral reefs.

The Earth has ten major terrestrial biomes: tropical rain forest, tropical dry forest, temperate rain forest, temperate deciduous forest, boreal forest (taiga), savanna, chaparral, temperate grassland, tundra, and desert. The following chart summarizes the main characteristics of each biome.

Characteristics of Earth's Terrestrial Biomes					
Biome	**Precipitation**	**Temperatures**	**Biotic Forms**	**Locations**	**Other**
Tropical rain forest	High year-round	Warm throughout the year	Lush; high biodiversity	Central America, South America, Southeast Asia, West Africa	Soils are acidic and lack nutrients because most nutrients are within the vegetation; near equator
Tropical dry forest	Low overall, but seasonal; rainy half the year, dry half the year	Warm year-round	Adapted for seasonal fluctuations; deciduous plants	India, Africa, South America, northern Australia	
Temperate rain forest	High year-round	Moderate	Coniferous trees (firs, cedars, spruces), mosses, moisture-loving species	Pacific Northwest of the United States, Japan	
Temperate deciduous forest	Spread evenly throughout year	Varied seasonally	Deciduous broadleaf trees	Europe, eastern China, eastern North America, southern Great Lakes in the United States	Fertile soils
Boreal forest	Long cold winters, short cool summers	Moderate	Evergreen forests; mainly feed and breed in warm, wet months; includes wolves, moose bear, lynx, and many migratory birds	Canada, Alaska, Russia, Scandinavia	Has many bogs and lakes; poor nutrients in the soil, which is also somewhat acidic; also known as taiga

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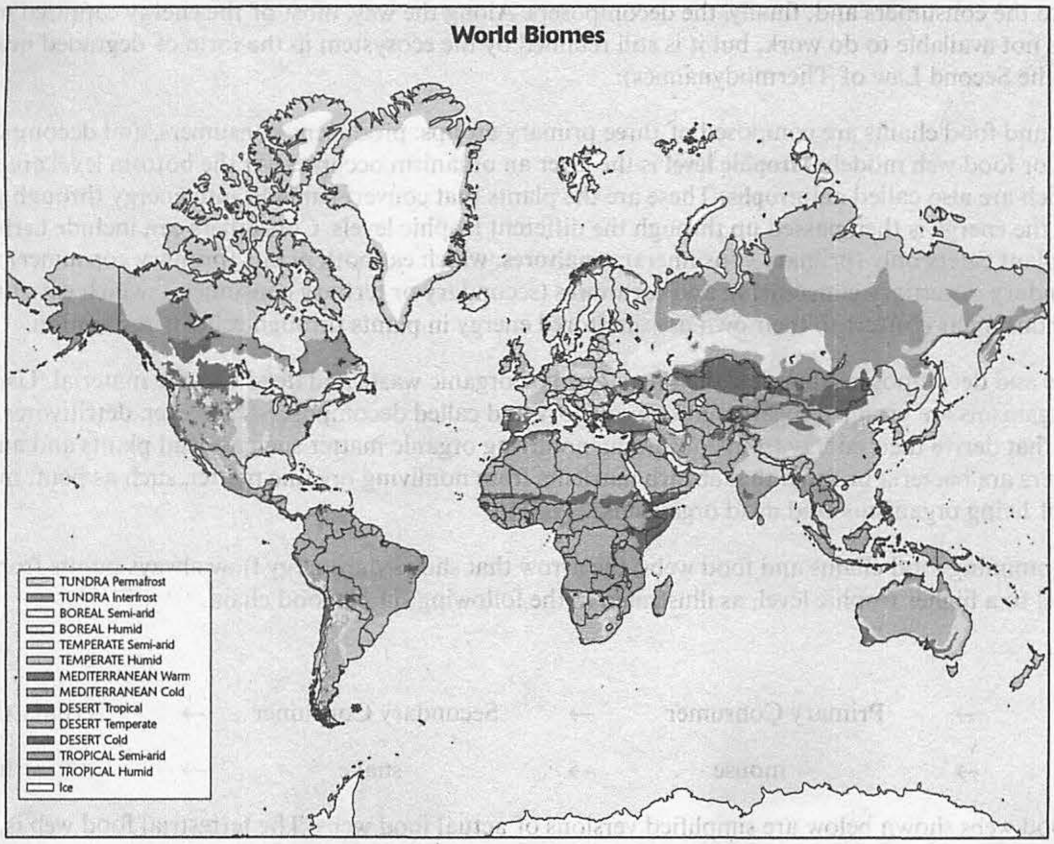
Biome	Precipitation	Temperatures	Biotic Forms	Locations	Other
Savanna	Short rainy season with increased rainfall	Warm; slight seasonal variation	Grasslands with groups of acacias and other trees; includes zebras, gazelles, lions, hyenas, and giraffes	Africa, South America, Australia, India	Animals gather near watering holes
Chaparral	Very seasonal with wet winters and dry summers	Mild winters, warm summers	Evergreen shrubs	California coast in the United States, Chile, Southern Australia, land surrounding the Mediterranean Sea	Has frequent fires, which helps some seeds germinate; sometimes called a Mediterranean climate
Temperate grassland	Low	Extreme differences between summer and winter	Mainly grasses due to low rainfall; includes bison, prairie dogs, antelope, and prairie chickens	North America, South America, central Asia	Much has been cleared for agriculture; also known as steppe or prairie
Tundra	Very low	Cold winters and cool summers	Lichens, low vegetation; most animals cannot survive all year and migrate, such as caribou and birds; polar bears and musk oxen live here year-round	Arctic Russia, Canada, Scandinavia, Alpine, High Mountain Alps, Rockies, and Andes	Short winter days and long summer days; located in high latitudes; soil remains frozen permanently (permafrost)
Desert	Extremely low; the driest biome	Dramatic variation between day and night; limited vegetation and humidity to hold heat at night	Some deserts are mostly bare and some have limited vegetation such as cacti; kangaroo, mice, and rattlesnakes live here; organisms develop adaptations to survive the extreme environment, including plants with green trunks to conduct photosynthesis without leaves, and animals that are nocturnal	Africa, Arizona in the United States, northwest Mexico	Soils are usually saline with a high mineral content and low organic matter



Source: U.S. Department of Agriculture

Energy Flow

Photosynthesis and Cellular Respiration

Photosynthesis is one of the most important biological processes for living organisms because. Through photosynthesis, most life on Earth obtains energy from the sun, directly or indirectly. The only exceptions are the chemosynthetic organisms that live at heat vents in the oceans and geysers in terrestrial systems.

Photosynthesis occurs when plants take in carbon dioxide (CO_2) and water (H_2O) while absorbing energy from the sun. The absorption takes place in their chloroplasts and produces glucose (a carbohydrate, $C_6H_{12}O_6$) and oxygen (O_2). **Cellular respiration** (or just respiration) is the process of "burning" the carbohydrate glucose in the presence of oxygen to release the stored energy for use by the organism.

The balanced chemical reaction for photosynthesis is $6\ CO_2 + 6\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$, where glucose ($C_6H_{12}O_6$) is the initial storage of energy in plants. This energy is then released by cellular respiration in the balanced reaction $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + \text{energy}$. This released energy is usable by the plant or animal for a variety of other internal chemical and energy transfer reactions.

Food Webs and Trophic Levels

Food webs are models made up of multiple overlapping food chains. A **food chain** is a simple layer of energy flow from the producer to various consumers. A food web represents more realistic and complex flow of energy from the producers to the consumers and, finally, the decomposers. Along the way, most of the energy captured in the food web is not available to do work, but it is still retained by the ecosystem in the form of degraded heat energy (following the Second Law of Thermodynamics).

Food webs and food chains are composed of three primary groups: producers, consumers, and decomposers. In a food chain or food web model, a **trophic level** is the layer an organism occupies. At the bottom level are the producers, which are also called **autotrophs**. These are the plants that convert sunlight into energy through photosynthesis, and the energy is then passed up through the different trophic levels. Consumers can include **herbivores,** which are plant eaters only (primary consumers); **omnivores**, which eat both plants (primary consumer) and animals (secondary or tertiary consumers); and **carnivores** (secondary or tertiary consumers), which eat other animals. The consumers convert to their own use the stored energy in plants through cellular respiration.

Detritivores and decomposers complete the breakdown of organic waste and dead organic material. Usually both types of organisms are grouped together in one category and called decomposers. However, detritivores are organisms that derive their energy from consuming nonliving organic matter such as dead plants and animals. Decomposers are bacteria or fungi that absorb nutrients from nonliving organic matter, such as plant material, the waste of living organisms, and dead organisms.

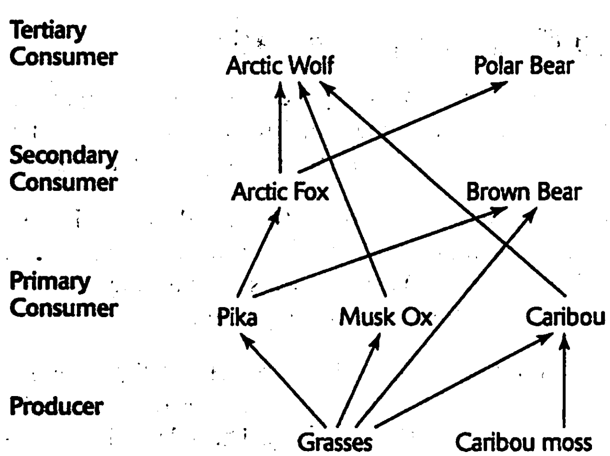
When diagramming food chains and food webs, the arrow that shows the energy flow always points from a lower trophic level to a higher trophic level, as illustrated in the following simple food chain.

Food Chain

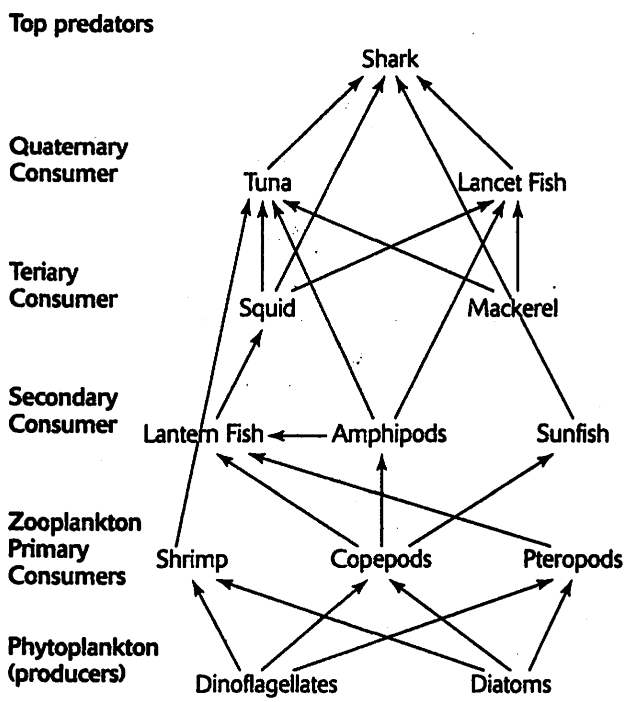
Producer	→	Primary Consumer	→	Secondary Consumer	→	Tertiary Consumer
grass	→	mouse	→	snake	→	hawk

The two food webs shown below are simplified versions of actual food webs. The terrestrial food web is from the Arctic, and the marine water food web can be found in oceans throughout the world. The direction of the arrows shows the flow of energy. Energy flows from the lower trophic level to the higher level.

Terrestrial Food Web



Marine Water Food Web



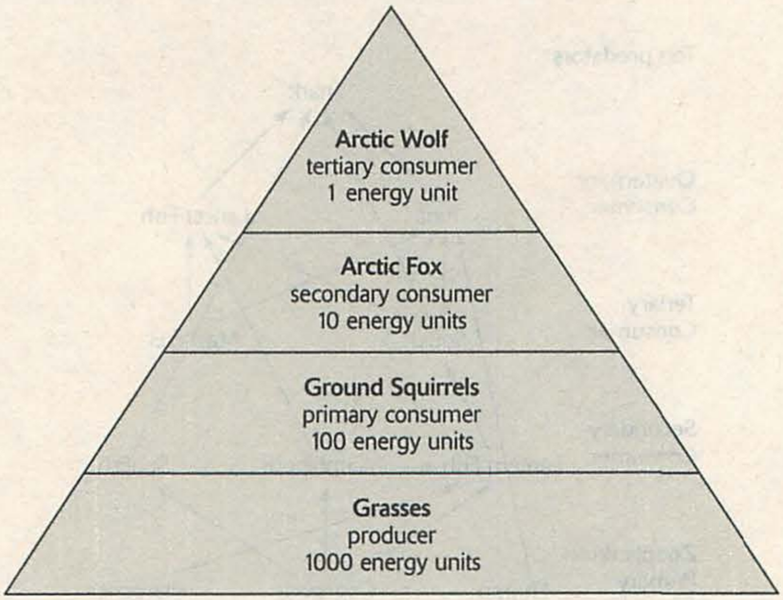
Ecological Pyramids

An **ecological pyramid,** also called an energy pyramid, is a diagram that shows the loss of available energy at each trophic level. Some energy is transformed into heat, which enters the environment and cannot be used. Losses may be caused by the incomplete digestion of food, incomplete capture of energy released during cellular respiration, or degradation of energy into heat energy.

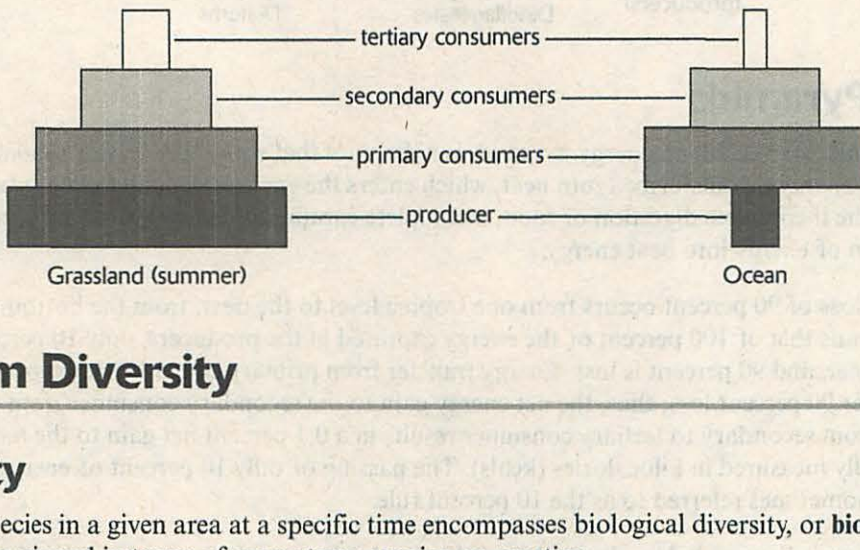
An average energy loss of 90 percent occurs from one trophic level to the next, from the bottom of the pyramid to the top. That means that of 100 percent of the energy captured in the producers, only 10 percent of it moves to the primary consumer, and 90 percent is lost. Energy transfer from primary consumer to secondary consumer accounts for another 90 percent loss; thus, the net energy gain to the secondary consumer from the system is 1 percent. Transfer from secondary to tertiary consumer results in a 0.1 percent net gain to the tertiary consumer. This energy is usually measured in kilocalories (kcals). The passing of only 10 percent of energy from one trophic level to the next is sometimes referred to as the 10 percent rule.

The Pyramid of Energy diagram below shows the trophic levels of an arctic food pyramid which indicates an organism's energy level of consumption. The numbers indicate the amount of energy available to consumers at that level. The energy decreases moving up the pyramid due to energy lost. The Pyramid of Biomass represents the biomass at each trophic level in both a grassland ecosystem and an aquatic saltwater ecosystem. In the ocean pyramid, the mass of producers in the open ocean may be relatively small compared to consumers. This is because they grow and reproduce rapidly and are able to produce enough energy to support the species in higher trophic levels.

Pyramid of Energy



Pyramid of Biomass



Ecosystem Diversity

Biodiversity

The total of all species in a given area at a specific time encompasses biological diversity, or **biodiversity.** Biodiversity can be viewed in terms of ecosystems, species, or genetics.

- **Ecosystem diversity** is the variety of ecosystems within a specific area, including communities and habitats. An ecosystem includes all living organisms in an area. A large section of prairie land will have lower biodiversity than a forested area with many different varieties of trees supporting many types of species.
- **Species diversity** is the number (or variety) of a species within a particular community. A **species** is classified as a group of organisms that share particular sets of characteristics and can breed and reproduce to create fertile offspring. The higher number of different species in an area means there is high biodiversity. In evaluating species diversity, there are two key components: species richness and relative abundance. **Species richness** is the number of species in an area, while **relative abundance** is the number of each species in relation to one another, or how equal the numbers are of each species.
- **Genetic diversity** is the variation of heritable DNA among individuals of a species or population. All organisms have different DNA makeup, so a population of organisms with a large number of individuals *will*

have more genetic diversity than a population with a few individuals. Populations with low genetic diversity are at higher risk for extinction because fewer genetic variations are available to allow for adaptation to environmental change. As an example, if the climate in a region is altered dramatically and becomes warmer, the organisms with thicker fur may not survive, thus leaving those with thinner coats to survive and reproduce. Also, if only a few individuals have this variation, the whole population could suffer. In addition, low genetic diversity can lead to inbreeding issues when organisms with a very similar genetic makeup breed and produce offspring with physical problems.

Biodiversity is not evenly distributed because factors such as climate, altitude, and topography affect what species live in particular locations. Species richness is greater closer to the equator. This difference in richness from poles to equator is called the **latitudinal gradient** and is supported by the consistent amount of solar radiation, humidity, and precipitation near the equator. The result is increased plant life near the equator, which, in turn, supports numerous animal populations.

Evolution and Natural Selection

Biodiversity on Earth has been created through the process of **evolution,** the variation in genetic makeup of a population of organisms through generations. Genetic changes take place in organisms within a population over many generations, occurring randomly or through the process of natural selection. **Natural selection** results when genetic traits that strengthen an organism's chance of survival and reproduction are passed on from generation to generation, ultimately altering the genetic makeup of a population, creating a new species. In the process of natural selection, some organisms in a population are better suited to survive than others; therefore, the organisms that survive are those that have a reproductive advantage and are more likely to pass on their genes. Across time, entire populations contain traits that increase the likelihood to adapt, survive and reproduce.

The traits that lead to success are **adaptive traits,** or **adaptations.** For these traits to be passed on to offspring, genes in an organism's DNA must code for that trait. During DNA replication, which occurs in an organism's cells millions of times throughout its life, errors can arise. These errors lead to accidental alterations in DNA, called **mutations.** Most mutations don't have an effect, but some can be favorable and some can be fatal. The positive mutations can lead to a better ability to survive and reproduce in an environment, leading to natural selection. These mutations also can occur through mating, when genetic material combines during sexual reproduction.

If not enough individuals in a population have traits that help them survive and reproduce in a changing environment, then the chance is higher that the species will dwindle in numbers and possibly go extinct. The Monteverde golden toads are one example. (See the Case Studies in Appendix B for additional information about the Monteverde golden toad.)

The environment plays a key role in determining which traits are beneficial; thus, an organism's environment as well as genetic makeup affect natural selection and ultimately the evolution of a species.

Artificial selection occurs when humans have an impact on which traits are selected during breeding. Examples of species that have been artificially selected include dogs, cats, horses, cows, and many types of flowers.

Types of Selection

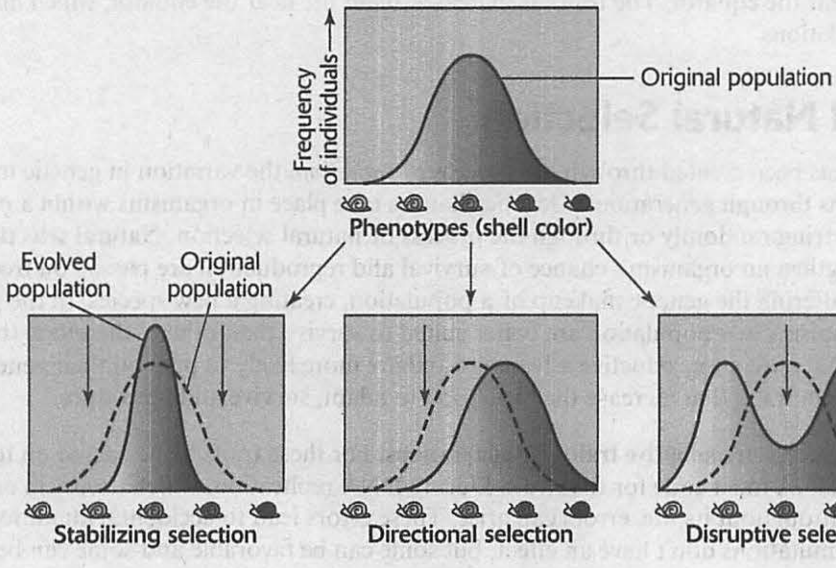
Three models of natural selection have been described:

- **Stabilizing selection** occurs when a population's characteristics stay within a moderate range and neither extreme is dominant. If individuals fall away in either extreme, their chances of survival are reduced. This structure reduces evolutionary change and diversity. For example, birds are important to flower pollination. If a bird's beak is too short or too long, it will not effectively reach and transfer pollen between flowers; therefore, a medium-length bill is most effective and most common.
- **Disruptive selection** discriminates individuals with characteristics at the extremes, so fewer individuals fall within the average. With this model structure, evolution does occur, as individuals fall to either extreme in

the population. As a general example, in an area that has small and large seeds for the bird population to eat, but no medium seeds, birds with small and large beaks will dominate while birds with medium-sized beaks will be present in low numbers.

- **Directional selection** favors one extreme of the population, so the opposite extreme and the average in the model are not where the majority of a population falls. As with disruptive selection, evolution does occur. An example is the peppered moth. At one time, most of these moths were light in color, but following increases in pollution from the Industrial Revolution, the species shifted and darker moths became more abundant than lighter individuals.

Types of Selection



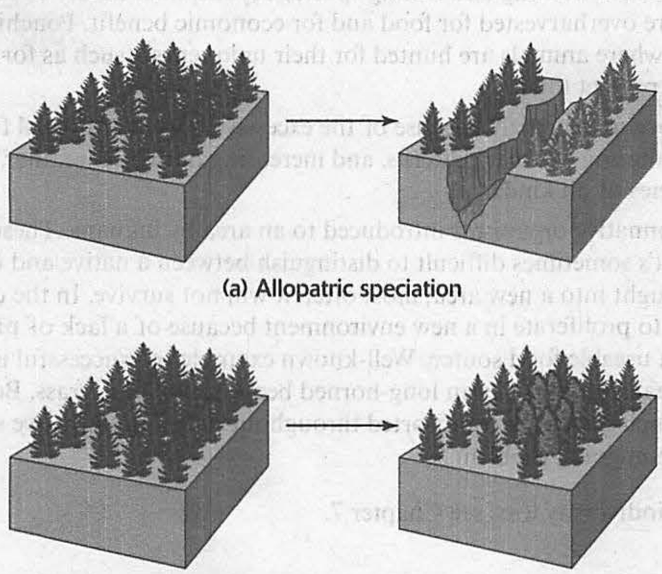
Speciation

Speciation is the process by which new species are created. This process can occur in many ways but two are common: allopatric and sympatric. **Sympatric speciation** occurs when similar organisms live within the same location but fulfill different niches; therefore, they do not mate and reproduce. The most common way speciation occurs is through **allopatric speciation**, when a new species is created over time because of a physical separation of a population. Separation can result from physical changes such as:

- Formation of mountain ranges
- Rivers changing course
- Habitat fragmentation
- Advancement of glacial ice sheets
- Alteration of climate in a region
- Shift of ocean currents
- Formation of islands from volcanism

When a physical division takes place parts of a population are separated. As a result, the divided population can no longer reproduce with each other because of geographic distance. Over time each population develops and passes on new and different mutations. Given enough time, a new species may form because of the genetic variations in the populations. If at some point in time these different populations would reunite, they would no longer be able to interbreed. Speciation has occurred.

Speciation



(a) Allopatric speciation

(b) Sympatric speciation

Ecosystem Services

Benefits provided by ecosystems that help support life on Earth, and in many cases the human economy, are known as **ecosystem services.** A few examples of such services include the cycling of nutrients, purification of air and water, creation of soil, and the supplying of raw materials.

Without these services offered by the environment, life would not be able to flourish and survive. For humans, our economic structure would not exist without its raw materials for industry, beauty to support tourism, or the natural cleaning and recycling it enables. Major benefits afforded to humans include food security, tourism and recreation, drugs and medicine, and a connection to nature and other life (referred to as **biophilia**).

Biodiversity is the key to ecosystem services. Because of the diversity of species in an area, an ecosystem is better able to remain stable or recover quickly after a disturbance.

Biodiversity Loss, Conservation, and Extinction

Biodiversity Loss

Species and biodiversity are being lost at an extremely rapid rate, largely because of human activities. Such activities include habitat alteration, pollution, overharvesting, climate alteration, and introduction of invasive species, each of which can harm a particular population of a species and potentially put the entire species at risk. **Extinction** occurs when all populations of a species are lost and no individuals remain. On a smaller scale, **extirpation** is the point at which a population vanishes from a particular area but remaining populations are still in other locations on the planet.

- **Habitat alteration** results from any human activity that changes an ecosystem. Deforestation, farming, mining, development, and dams are examples of activities that affect habitats. Habitat alteration is the largest contributor to biodiversity loss and population declines.
- **Pollution** can affect the water, air, and soil, all of which have an impact on not only the local ecosystem and its organisms but also those in distant areas as well because pollution can be transported far from its source. Pollution also has a detrimental effect on human health (see Chapter 6).

- **Overharvesting** results from hunting and fishing species beyond their ability to recover the numbers of their population. Species are overharvested for food and for economic benefit. Poaching is still an issue in some regions of the world, where animals are hunted for their uniqueness (such as for elephant tusks and tiger claws) despite laws to protect them.
- **Climate alteration** is occurring partly because of the excessive burning of fossil fuels, which is increasing global temperatures, altering weather patterns, and increasing dramatic weather, ultimately changing the climate globally for species of all kinds.
- **Invasive species** are nonnative organisms introduced to an area by humans. These species are so numerous and widespread that it's sometimes difficult to distinguish between a native and invasive species in an area. When a species is brought into a new area, most often it will not survive. In the case of invasive species though, they are able to proliferate in a new environment because of a lack of predators and disease as well as the availability of a useable food source. Well-known examples of successful invasive species include zebra mussels, European starlings, Asian long-horned beetles, and cheatgrass. Because of the global economy and ease with which goods are transported throughout the world, invasive species are continually being introduced and are an ongoing problem.

For more information on biodiversity loss, see Chapter 7.

Conservation

Conservation biology studies the environment and biodiversity in an effort to protect species and their habitats. Through these studies, solutions are developed to address habitat loss and species loss.

People are trying to protect and conserve our natural world in many ways. Nonprofit organizations, communities, and individuals bring awareness and take initiative to protect habitats and wildlife, and laws and policies are put in place to support conservation efforts.

Many laws and initiatives have been established to support conservation efforts on local, regional, national, and global scales. For example, in the United States the **Endangered Species Act** (ESA) does not allow governments or private citizens to perform actions that would affect endangered species and their habitats. Internationally, the **Convention on International Trade in Endangered Species of Wild Fauna and Flora** (CITES) bans the transporting of body parts of endangered species internationally.

Extinction

Without human efforts to conserve and protect the environment, the reality of extinction can come to fruition. Throughout Earth's history, most species have disappeared over time and gone **extinct**. On average, species spend between 1 million and 10 million years on this planet, depending on a variety of factors. Because the process of natural selection doesn't happen rapidly—it takes a multitude of generations to occur—if an environmental change occurs abruptly, species do not have time to adapt and may go extinct. Environmental change can take place for many reasons, such as a rise in sea level, climate fluctuations, arrival of invasive species, and natural disasters.

Extinction is a natural process, although in many cases it has been accelerated by humans. Species that are **endemic** to an area, or occur in only one location on the planet, are more susceptible to these changes, as are species that are considered **specialists**, filling a narrow niche in their ecosystems.

When extinctions happen gradually over time, the rate at which they occur is considered to be the **background extinction rate**. When extinction occurs relatively quickly and on a large scale, affecting many species, it is considered a **mass extinction event**. So far, there have been five known mass extinction events and each has killed between 50 percent and 95 percent of all species on Earth. Because of the brisk rate at which species are presently being lost, some say that the sixth mass extinction event is underway, this time at the hands of humans.

Natural Ecosystem Changes

Climate Shift

Over geologic time, the Earth's climate naturally shifts as the planet changes and evolves. In the past one billion years, the Earth has experienced six glacial periods. Currently, the Earth is in a period of glacial retreat called the Holocene epoch, which started about 14,000 years ago. Within this epoch, though, is a brief time period that is an exception to this retreat. The 1500s to the 1800s were a time of cooling, and because it was the coldest climate since the Holocene began, it has been termed the "Little Ice Age." From the mid-1800s to present times, there has been a period of general warming. Some of this is natural, but many people think it is a result of human activities.

Natural climate shifts can be caused by many changes on Earth. The following are events that can alter the Earth's climate:

- Volcanoes block solar radiation from reaching the Earth's surface, creating a cooling effect.
- Continental drift alters oceanic currents and atmospheric winds, both of which impact the distribution of heat on the planet and the altering of water evaporation into the atmosphere.
- Earth's tilt can change, which affects seasons and the amount of sunlight reaching various parts of the planet.
- Comets and meteorites can have a catastrophic impact on Earth, sending debris and clouds into the atmosphere and blocking solar radiation.
- Geomagnetic reversals may cause localized climate shifts and are currently being researched.

Human activities that can alter the climate include the extensive combustion of fossil fuels and deforestation. For more information on human-induced climate change, see Chapter 7.

Species Movement

As climates have shifted and changed during the coming and going of the ice ages, species have either adjusted or died out. Plant species, which can't physically move, must adjust where they grow or face extinction. Plants can spread by a variety of methods: seeds can blow in the wind, attach to animals and drop a great distance away from the original plant, or pass through the digestive systems of animals and be spread as the animals migrate. Plants may spread slowly along the edge of their ranges to extend their territory. Since most ice ages take long periods of time to form and retreat, plants can adjust their territory as the climate shifts.

Still, animals may have an easier time adjusting to a changing climate because many have the ability to move. As the climate shifts, animals can more easily change their territory as long as suitable habitat is within reach. Even the smallest of animals have shown evidence of moving as climate changes.

Ecological Succession

Communities are not static but are constantly changing. Species of plants and animals come and go, evolve and die out. Change is constant, although often slow by human standards. Change in a given geographical area that is predictable is described as **ecological succession.**

Two types of ecological succession have been identified:

- **Primary succession** is the process that starts with bare rock where no soil or life are present, such as a new volcanic island, an area emerging from beneath a retreating glacier, or the Earth when it was very young.
- **Secondary succession** is the re-growth of an area after an event has wiped out an existing community, but soil and some life remain. The "event" might be a fire, tornado, volcanic eruption, or human activity. Examples of human activities are abandoning an agricultural field to regrow on its own, clear-cutting a forest, or setting a fire.

The organisms that start succession in both types are called **pioneer species.** These species typically have a wide range of environmental tolerances and generally include lichens, mosses, algae, and bacteria. The pioneer species lay the foundation of nutrients on which succeeding species come and settle. Grasses are typically second; they add organic material to the developing soil and hold the new soil in place with their root systems. Small herbaceous plant species appear next, and they continue to add organic matter to the soil. Small bushes join the mix, adding still more organic matter but, more important, adding shelter and shade to the area for other plants yet to come. Conifers appear and add to the growing habitat. Short-lived hardwoods move in (such as the maples), and finally the climax community of long-lived hardwoods (such as the oaks) is reached. The succession of animals follows a similar pattern: insects are the first to arrive, and then small rodents and lizards. Birds come and bring with them the seeds of new plants for the community. As the community becomes more complex, larger mammals join the changing ecosystem.

How long this process takes depends on whether the area is undergoing primary or secondary succession. Another driving force is the climate; areas in dry climates take longer to develop than those in moist climates. Areas that receive large amounts of precipitation may also take longer to develop because the newly accumulating nutrients can be washed away by flowing water. Obviously an area undergoing primary succession will take much longer to fully develop than one in secondary succession. Secondary succession is also driven by the proximity of returning organisms. The size of the disturbed area and how close the former members of the community are to the area will play a determining factor in the succession of the area.

Biogeochemical Cycles

Biogeochemical cycles (nutrient cycles) describe the movement of nutrients throughout ecosystems (movement between Earth's abiotic and biotic systems). The word *biogeochemical* is a combination of *bio* (meaning "life"), *geo* (meaning "earth"), and *chemical* (meaning "elements or compounds that cycle through the living and nonliving world"). While many nutrients are essential for life and health on our planet, five nutrient cycles are vital for ecosystem function and survival: carbon, oxygen, nitrogen, phosphorus, and sulfur. These five nutrient cycles are being altered by human activity.

Key components of each cycle include where the nutrients are stored, how long they remain in the storage areas, and the process of movement between the living and nonliving parts of each cycle. Nutrient storage is commonly referred to as **reservoirs** or **sinks.** These reservoirs may be different for each nutrient or they may be common, depending on the nutrient. How long they remain depends on whether the nutrients are in living organisms or nonliving components. In living organisms, a reservoir may exist for only a few hours (in some bacteria) or as long as several thousand years (in a redwood or bristlecone pine). In the nonliving components, nutrients could be locked up for millions or even billions of years, either in the atmosphere or Earth's crust. The movement of each nutrient between the living and nonliving is described in each nutrient cycle.

Carbon Cycle

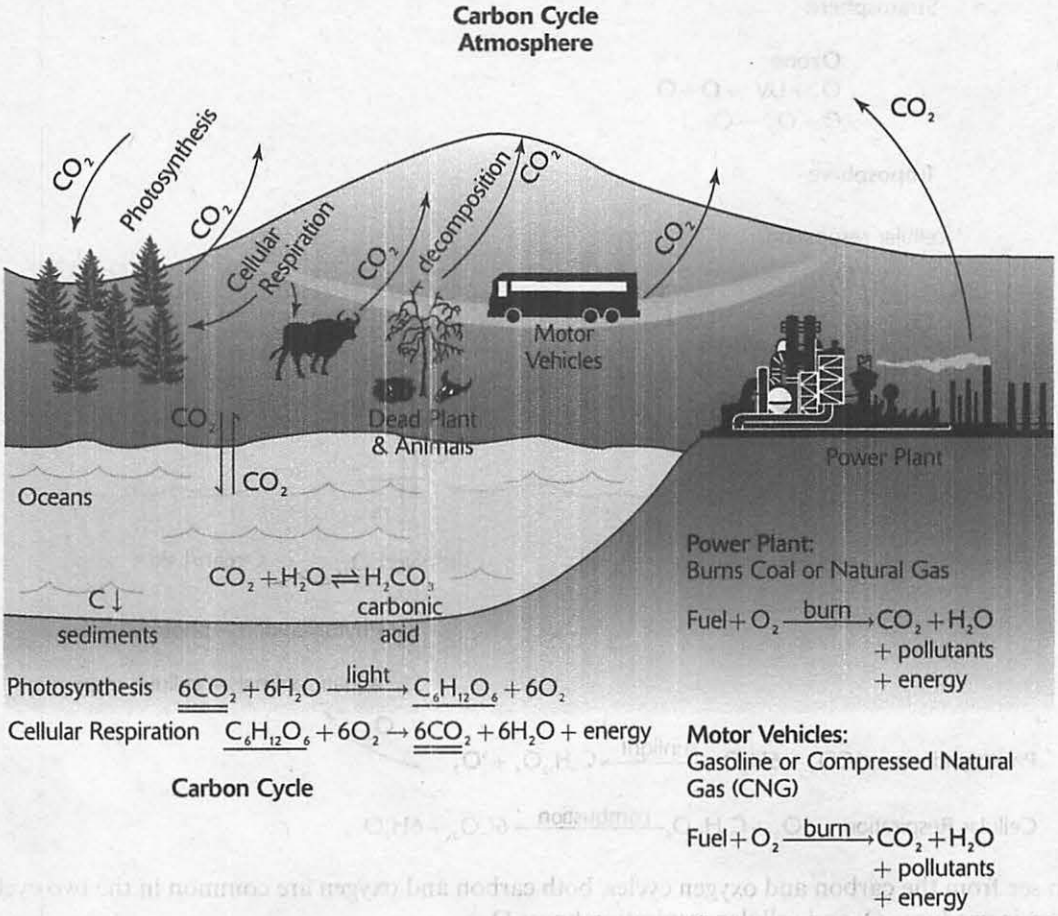
As a major part of life, carbon exists on Earth in living organisms, decomposing components of ecosystems, and in abiotic factors of the environment. Also, it is found in gaseous and solid states. Carbon enters living organisms through plants when CO_2 is converted to carbohydrates during photosynthesis. Carbon moves through animals when they consume plants and other animals. Carbon is released into the atmosphere in the form of CO_2 during cellular respiration and when decomposers break down the remains of dead plants and animals.

The major reservoirs of the carbon cycle include plants, oceans, and sedimentary deposits. Plant matter, while a small sink, is one that humans must consider as we grow more plants and animals for human food consumption. Some of this carbon is stored for a short time, such as in the annual plants we grow for food, while other carbon is stored for thousands of years in giant sequoias, for example. Because plants are constantly releasing and capturing CO_2, they are considered to cause zero change in the atmosphere.

Carbon dioxide is soluble in water, so the world's oceans are a major sink for carbon. It is dissolved in the world's oceans just as oxygen is dissolved. This dissolved CO_2 is important for aquatic plant photosynthesis. Carbon is also found in the shells and skeletons of marine organisms. An exchange of CO_2 occurs between the atmosphere and marine waters. Because of the net increase in CO_2 in the atmosphere from the combustion of fossil fuels, it is believed that the world's oceans are becoming more acidic.

Earth's rocks contain some carbon, although silicon and oxygen are their primary components. Rocks that contain carbon are called carbonate rocks, and the form of carbon is calcium carbonate.

A final sink and the form that is the primary focus of human interventions in the carbon cycle is the carbon in coal, gas, and crude oil, what we refer to as fossil fuels. This carbon—originally from living organisms that have undergone a chemical change over time, with pressure and heat, to be converted into coal and oil—has been sequestered for millions of years. Thus, the combustion of fossil fuels has contributed to a shift from carbon stored in the lithosphere to the atmosphere, creating a net gain of CO_2 in the atmosphere.



Oxygen Cycle

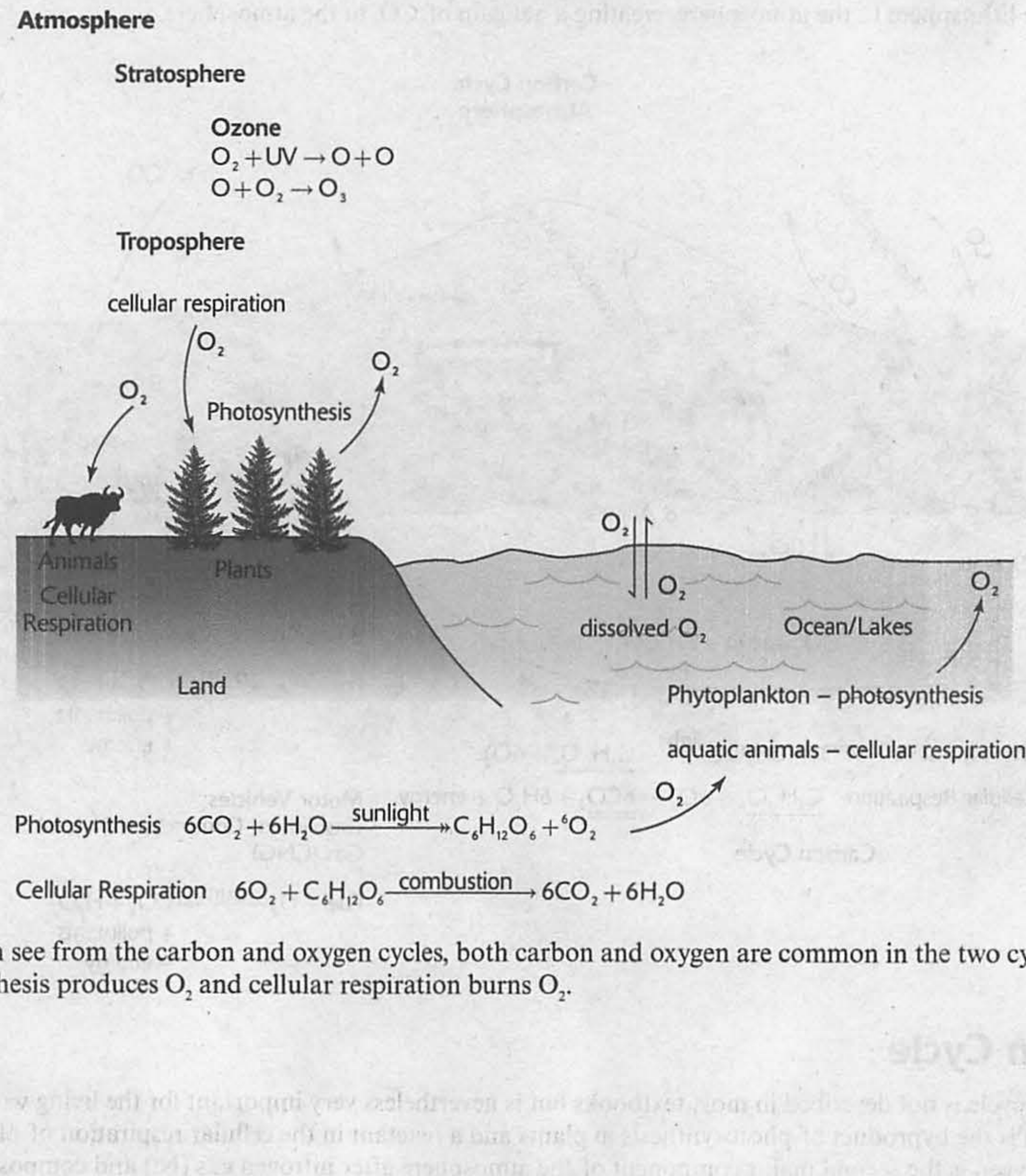
The oxygen cycle is not described in most textbooks but is nevertheless very important for the living world. Oxygen (O_2) is the byproduct of photosynthesis in plants and a reactant in the cellular respiration of plants and animals. Oxygen is the second major component of the atmosphere after nitrogen gas (N_2) and composes approximately 21 percent of the atmosphere.

Oxygen is a reactive molecule. Besides involvement in the photosynthetic and cellular respiration reactions, oxygen is removed from the atmosphere during the weathering process of rock and minerals. As new rock and minerals are exposed to the atmosphere during weathering, oxygen combines with them in a process called oxidation and is, thus, removed from the atmosphere.

Oxygen is also important in the formation of atmospheric ozone. Sunlight breaks water (H_2O) vapor into hydrogen gas and oxygen, and the hydrogen escapes Earth's atmosphere and travels into outer space. Ozone (O_3) is a naturally occurring reaction product in the atmosphere, where it forms a layer. The ozone layer is important for filtering out much of the harmful ultraviolet (UV) radiation from the sun and keeping it from hitting the Earth. The chemical reaction for the formation of ozone is:

$$O_2 + UV \rightarrow O + O$$
$$O + O_2 \rightarrow O_3$$

Oxygen Cycle



As you can see from the carbon and oxygen cycles, both carbon and oxygen are common in the two cycles. Photosynthesis produces O_2 and cellular respiration burns O_2.

Nitrogen Cycle

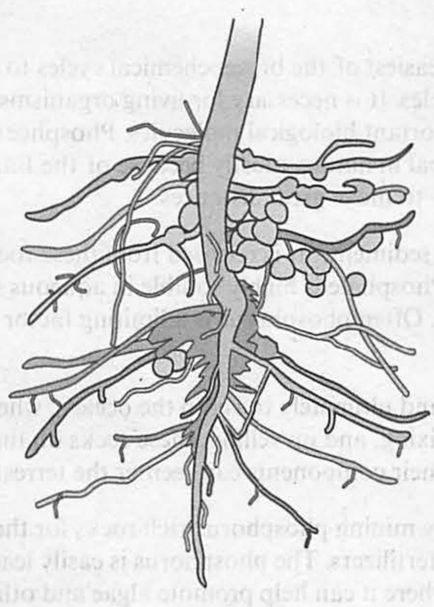
Our atmosphere is composed of 78 percent nitrogen and 21 percent oxygen. However, this atmospheric nitrogen cannot be used by organisms without some assistance. The nitrogen cycle is unique because it has stages during which bacteria help convert the nitrogen into useable forms. Nitrogen is essential for life because it helps to develop proteins, DNA, and RNA, and provide for plant growth. It can also be a limiting factor in plant growth.

The nitrogen cycle begins in the atmosphere as a gas (N_2). It then goes through many steps throughout its cycle.

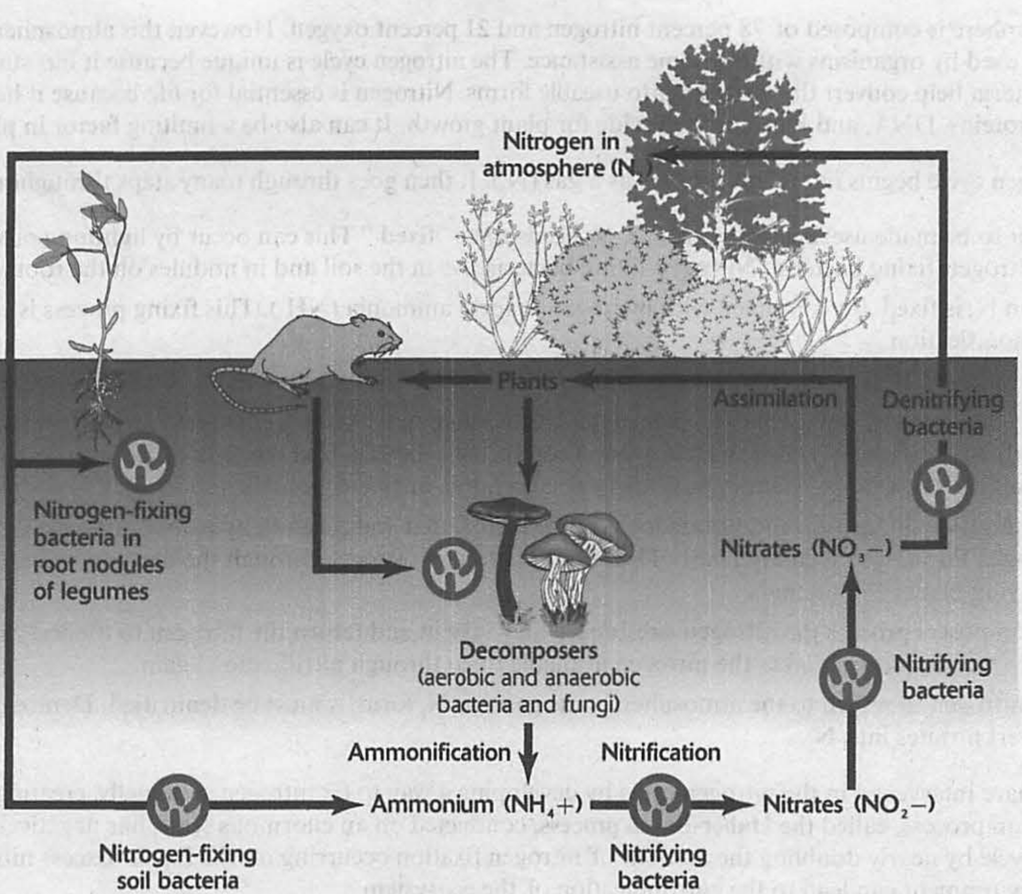
- For it to be made useable by organisms, N_2 needs to be "fixed." This can occur by lightning or with the help of nitrogen-fixing bacteria. Nitrogen-fixing bacteria live in the soil and in nodules on the roots of legumes.
- When N_2 is fixed, it's combined with hydrogen to form ammonia (NH_3). This fixing process is called ammonification.
- The water-soluble ion of NH_3 is ammonium (NH_4^+), which can be taken in by plants through their roots.
- NH_4^+ then goes through a process known as nitrification, in which it is converted into nitrite ions (NO_2^-) and then nitrate ions (NO_3^-). This process is conducted by specialized bacteria called nitrifying bacteria. These ions can also be taken in by plants since they, too, are water soluble.
- The ammonium, nitrite, and nitrate ions can be assimilated and taken in by plants. Animals then receive nitrogen through consuming plants. Decomposers receive nitrogen through the decomposition of waste and decaying plants and animals.
- Decomposers process the nitrogen substances they take in and return the nitrogen to the soil as ammonium ions. Decomposition makes the nitrogen available to go through nitrification again.
- For nitrogen to return to the atmosphere in its gaseous N_2 form, it must be denitrified. Denitrifying bacteria convert nitrates into N_2.

Humans have intervened in the nitrogen cycle by developing a way to fix nitrogen artificially, creating fertilizer. This fixation process, called the **Haber-Bosch process,** conducted on an enormous scale, has negatively altered the nitrogen cycle by nearly doubling the amount of nitrogen fixation occurring on the Earth. Excess nitrogen in an aquatic environment can lead to the eutrophication of the ecosystem.

Nodules on Plant Roots



Nitrogen Cycle



Source: Environmental Protection Agency

Phosphorus Cycle

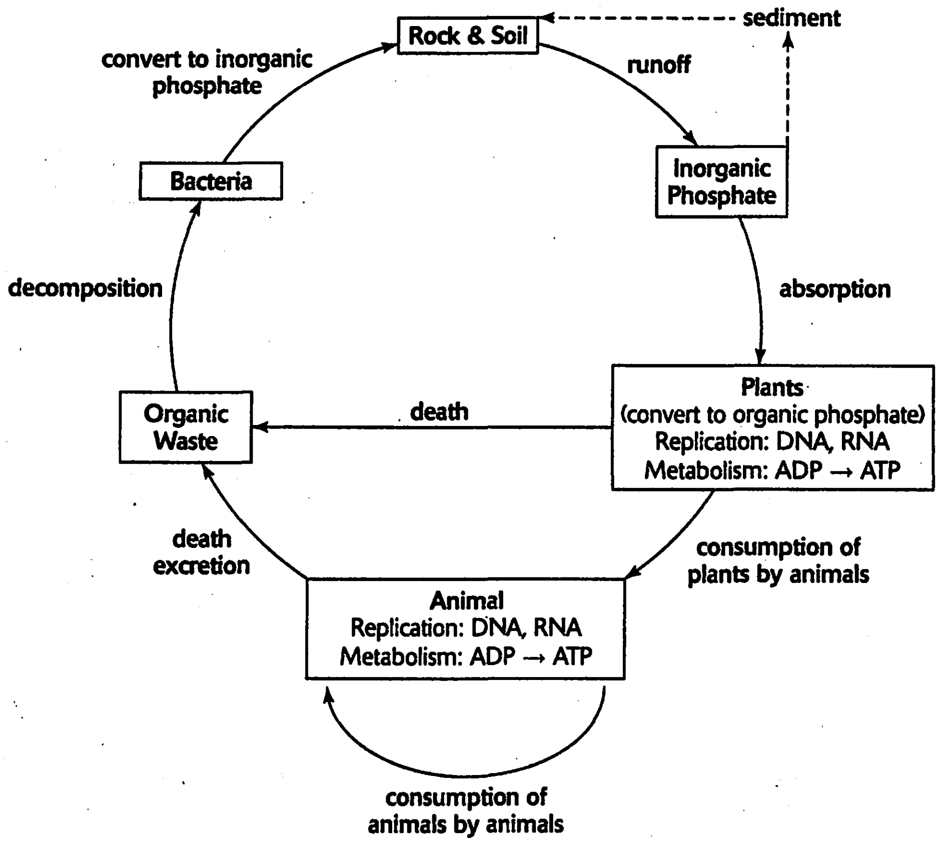
The phosphorus cycle is probably the easiest of the biogeochemical cycles to describe. Phosphorus does not exist in the atmosphere except in dust particles. It is necessary for living organisms, as it is the backbone of nucleic acids (DNA and RNA) and other important biological molecules. Phosphorus tends to move through a local cycle, whereas the other cycles are global in nature, mostly because of the Earth's weather. Since phosphorus is limited in the atmosphere, it is unlikely to move great distances.

Phosphorus is found in soil, rock, and sediments. It is released from these rock forms through chemical weathering in the form of phosphate (PO_4^{3-}). Phosphate is highly soluble in aqueous solutions and can be absorbed from the soil into plants through their roots. Often phosphorus is a limiting factor for plant growth, as little of it is released into the environment.

Phosphorus can enter the water table and ultimately travel to the oceans, where it settles on the ocean floor. Later, through geological processes, ocean mixing, and upwelling, these rocks on the ocean floor may rise and become new land surface, with the result that their components can reenter the terrestrial cycles.

Humans affect the phosphorus cycle by mining phosphorus-rich rocks for the purpose of processing them and adding them to commercial inorganic fertilizers. The phosphorus is easily leached into the groundwater and can find its way into aquatic ecosystems, where it can help promote algae and other aquatic plant growth that can lead to overgrowth of these plants and ultimately eutrophication of the pond or lake. Phosphorus also can be added to ecosystems by humans through the release of untreated sewage, agricultural runoff, and detergents.

Phosphorus Cycle



Sulfur Cycle

An important component of protein and vitamins, sulfur is essential for plant and animal health. Naturally, most sulfur is located in rocks and ocean sediments, but some is also found in the atmosphere.

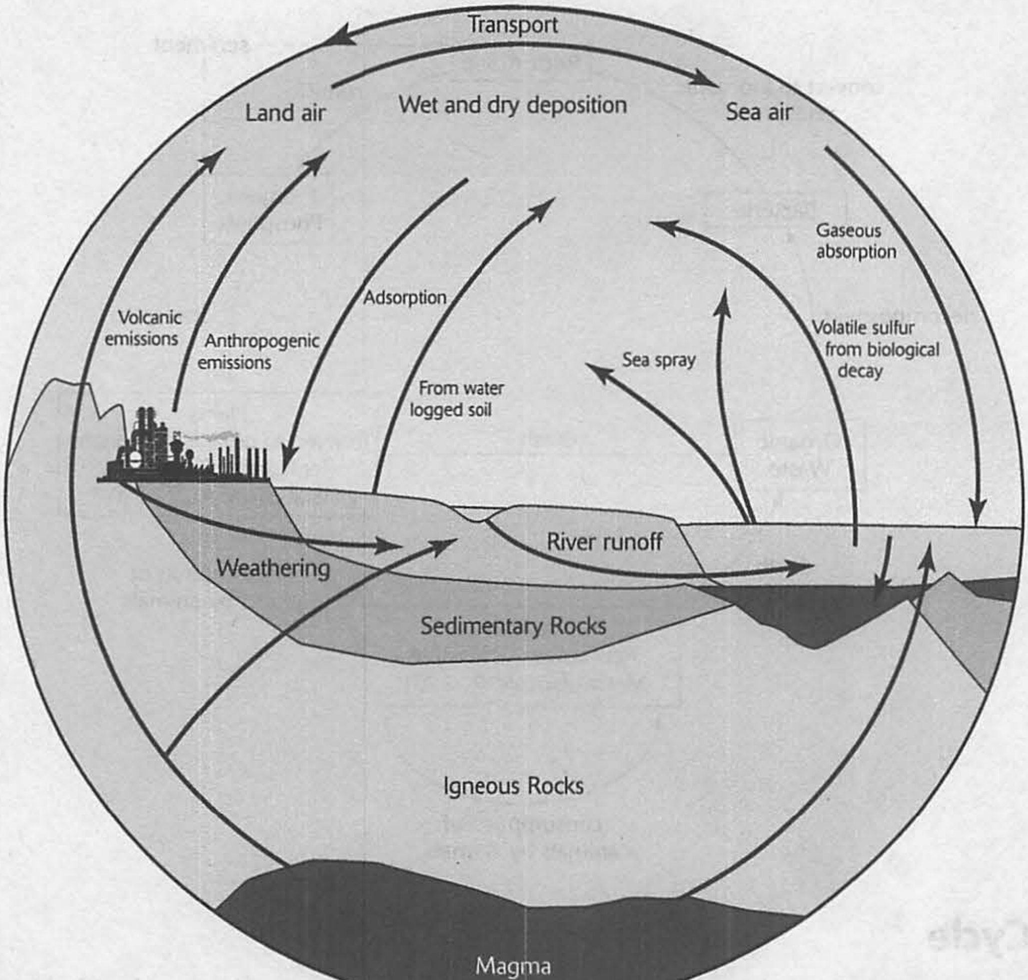
The natural sulfur cycle is described by the following path:

- Sulfur is naturally released into the atmosphere from rocks and sediment in the forms of hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) through weathering, volcanic eruptions, and the decay of dead organisms.
- Once in the atmosphere, SO_2 reacts with oxygen to form sulfur trioxide (SO_3) and with water to form sulfuric acid (H_2SO_4).
- Sulfur particles are deposited back into the soil and water, or they combine with water and fall in the form of acid precipitation.
- Plants absorb sulfate ions (SO_4^{2-}) through their roots, and animals receive sulfur by consuming plants.

Humans have also affected the sulfur cycle through industrial processes and coal burning, from which sulfur is emitted into the atmosphere in the forms of SO_2 and H_2SO_4.

In each biogeochemical cycle, matter is being cycled throughout ecosystems. This movement of nutrients throughout various parts of an ecosystem—both biotic and abiotic—exemplifies the conservation of matter, which states that matter cannot be created or destroyed.

Sulfur Cycle



Source: U.S. Geological Survey

Practice

1. How is solar energy used on Earth?
   I. Air circulation is partly a result of the heating of the Earth by solar energy.
   II. Solar energy is absorbed by chloroplast and used to convert carbon dioxide and water into glucose and oxygen.
   III. The water cycle is powered by solar energy.

   A. I only
   B. II only
   C. III only
   D. I and II
   E. I, II, and III

2. Which of the following is NOT true of food webs?

   A. Food webs are composed of multiple food chains.
   B. A food web shows the flow of energy from producers to consumers and, finally, to decomposers.
   C. In food webs, decomposers break down organic waste to return nutrients to the ecosystem.
   D. When diagramming food chains and food webs, the arrows should be drawn from the lower trophic levels to the higher levels to show the flow of energy.
   E. As energy is moved up the food web, most of it is conserved by the species in the next trophic levels.

3. Secondary succession is the regrowth of a disturbed area, and primary succession is the development from the beginning. Which of the following is primary succession?

   A. Changing soil to rock
   B. Changing ice to water
   C. Changing rock to soil
   D. Growth after a forest fire
   E. Formation of an island by volcanic action

4. The cycle most responsible for linking biogeochemical cycles is the:

   A. Carbon cycle
   B. Hydrologic cycle
   C. Nitrogen cycle
   D. Phosphorus cycle
   E. Sulfur cycle

5. Humans are disrupting the carbon cycle in ways that have resulted in increased levels of carbon dioxide in our atmosphere. Which of the following human activities are most directly responsible for this increase?

   A. Deforestation and the clearing of plants that absorb CO_2 through photosynthesis
   B. The addition of large amounts of CO_2 to the atmosphere by burning fossil fuels and wood
   C. The use of fertilizers and pesticides for agriculture
   D. A and B only
   E. All of the above

6. Which of the following is NOT true regarding oxygen?

   A. O_2 is a natural occurring gas in the atmosphere.
   B. O_2 is a byproduct of photosynthesis.
   C. O_2 is a reactant in cellular respiration.
   D. O_2 is the largest component of the atmosphere.
   E. O_2 is a very reactive molecule.

7. Which of the following is NOT true of phosphorus and the phosphorus cycle?

   A. Living organisms do not need phosphorus.
   B. Phosphorus tends to be more localized compared with other biogeochemical cycles that can move more freely in the global system.
   C. Phosphorus is generally found in rocks, sediments, and soil.
   D. Phosphorus does not exist in the atmosphere as a gas.
   E. Phosphorus is mined from phosphorus-rich rock, which is processed and then added to commercial inorganic fertilizers.

8. Which of the following examples would NOT be considered an adaptive trait?

A. Thicker fur coats on wolves in northern Canada
B. Echolocation in bats
C. Longer claws on rodents that dig in the soil for food
D. The ability for hummingbirds to maneuver in the air quickly
E. High water requirements of plants in the desert

9. Due to a major flood, a dam broke, altering the course of a river. A population of ground squirrels became separated due to the river's change of course. Over time, the divided population developed new adaptations and eventually created separate species. This is an example of

A. Sympatric speciation
B. Stabilizing selection
C. Allopatric speciation
D. Directional selection
E. Disruptive selection

10. All of the following are ways in which humans are contributing to extirpation and extinction of organisms EXCEPT through:

A. Introducing invasive species
B. Polluting land, water, and soil
C. Creating wildlife refuges
D. Altering the climate
E. Overharvesting resources

11. If a species is endemic to an area, it is:

A. Only found in one location on the planet
B. A generalist species
C. Less prone to extinction
D. Considered an invasive species
E. Almost always protected under the Endangered Species Act

Questions 12–14 refer to the following answer choices.

A. Predation
B. Mutualism
C. Competition
D. Herbivory
E. Parasitism

12. Organisms feed on another organism for nutrients, which also harms the organism being fed upon.

13. The algae and fungi working together in lichen, where neither organism is harmed and both benefit.

14. During a period of drought, various species are competing for the same water source.

15. The nitrogen cycle is unique in that atmospheric nitrogen cannot be converted directly by organisms into usable nitrogen. What is necessary in order for atmospheric nitrogen to be converted to usable nitrogen by organisms?

A. Ammonification
B. Denitrifying bacteria
C. Nitrifying bacteria
D. Decomposition
E. Nitrogen fixation

Answers

1. E All three statements are true. Solar energy is responsible for heating the Earth and for the formation of glucose and oxygen; it also powers the water cycle.
2. E Most energy is converted into a non-useable heat form that escapes into the environment.
3. C Choices A and D are both secondary succession. Changing rock to soil is accomplished by water, by weathering, and by lichen; this is a long process.
4. B The hydrologic cycle, also called the water cycle, moves components of the carbon, nitrogen, and sulfur cycles. Phosphorus usually is not found in the atmosphere unless it is in dust particles. Nitrogen- and sulfur-containing compounds combine with water to form acids, which fall to the Earth's surface as acid deposition. Carbon dioxide moves between the atmosphere and bodies of water such as lakes and oceans, where the dissolved carbon dioxide reacts with water to form carbonic acid.
5. D Cutting down trees and clearing other plants that absorb CO_2 for photosynthesis increases the amount of CO_2 in the atmosphere. In addition, the combustion of fossil fuels and wood also increases the amount of CO_2 in the atmosphere. The use of fertilizers and pesticides may have the opposite effect, reducing CO_2 in the atmosphere, by increasing plant growth.
6. D The other answers are all true. Oxygen is the second major component of the Earth's atmosphere (21 percent), far behind nitrogen (78 percent).
7. A The other answers are all true regarding the phosphorus cycle. Living organisms need phosphorus in their DNA and RNA molecules, as well as in the ADP-to-ATP reaction.
8. E Requiring large amounts of water in a desert environment would not benefit the plants. It would actually dramatically lower their chance of survival in an environment where water is scarce.
9. C Allopatric speciation occurs when a new species is created over time due to a physical separation of a population, including the changing of a river's course.
10. C Wildlife refuges serve as a safe haven for species, while also occasionally allowing hunting and fishing in order to regulate populations; species benefit from wildlife refuges.
11. B Endemic species are usually specialists, which fill a small, specific niche.
12. E Parasitism occurs when one organism uses another for food and nutrients, while also harming the other organism.
13. B In lichen the algae provides food for fungi through photosynthesis, while the fungi provide a safe environment in which algae can grow. In a mutualistic relationship, two or more species benefit one another, each helping the other.
14. C When different species compete for the same resource, it is considered interspecific competition.
15. E In order for nitrogen to be useable by organisms, it goes through the process of fixation, which can occur from lightning strikes or from nitrogen-fixing bacteria found on the roots of legumes or in soil.