4.1 CHARACTERISTICS OF TERRESTRIAL AND AQUATIC ECOSYSTEM

5.7.13 Types of ecosystem

Ecosystems are of different types. These can be artificially categorized as follows:

A. *Natural ecosystem*

1. *Terrestrial ecosystem*, such as forest, grassland, desert.

A *forest* is an ecosystem with a high density of trees and other woody vegetation.

Grassland ecosystems are areas where the vegetation is dominated by grasses and other herbaceous (non-woody) plants. Grasslands occur in regions that are too dry for forests but that have sufficient soil water to support a herbaceous plant canopy that is lacking in deserts.

A *desert* is an ecosystem that receives an extremely low amount of precipitation, less than enough to support the growth of most plants. Deserts are defined as areas with an average annual precipitation of less than 250 millimetres per year, or as areas where more water is lost by evapotranspiration than falls as precipitation.

2. *Aquatic ecosystem*, which may be further distinguished as:

Fresh water, which may be **lotic** (running water such as a river) or **lentic** (standing water such as lake, pond).

Marine, such as ocean, estuaries.

B. *Artificial* or *domesticated ecosystem*

These are maintained artificially by man by the addition of energy. For example croplands like maize, wheat, rice field etc., where man tries to control the biotic community as well as the physico-chemical environment.

Aquatic ecosystem

Aquatic ecosystems are commonly categorized on the basis of whether the water is moving (streams, river basins) or still (ponds, lakes) and whether the water is fresh, salty (oceans), or brackish (estuaries).

Marine ecosystem

Marine ecosystems are part of the earth's aquatic ecosystem. They include oceans, estuaries, salt marshes, lagoons, some tropical ecosystems, such as mangrove forests and coral reefs, rocky, subtidal ecosystems, and shores. The main difference between with other aquatic ecosystems is its salt content.

Oceans represent the largest and the most diverse type of ecosystem. Oceans can be divided into numerous regions depending on the physical and biological conditions. Oceans environment is generally classified on the basis of light penetration (photic and aphotic zones), distance from shore and water depth (intertidal, neritic and oceanic zones) and whether it is open water (pelagic zone; zone neither close to the bottom nor near the shore) or bottom (benthic and abyssal zones).

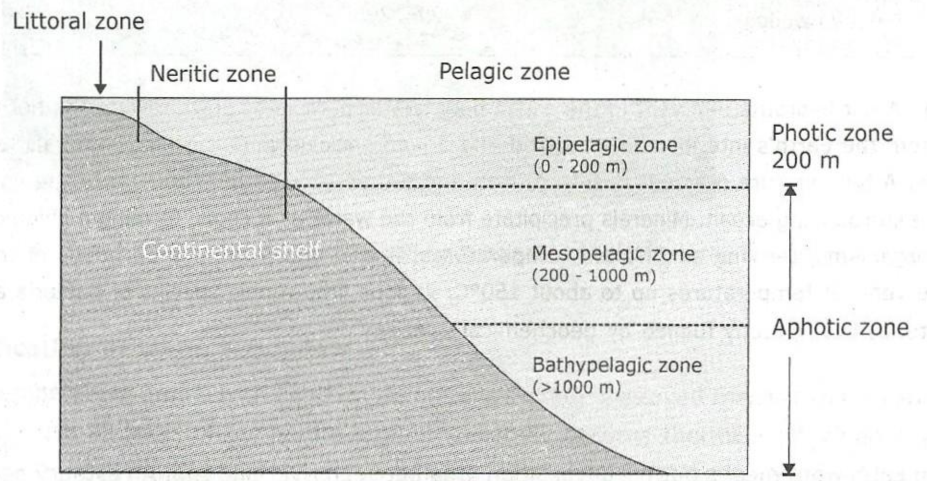


Figure 5.17 Zonation in marine ecosystem.

The **littoral**, or *inter-tidal zone* is the shoreline between land and open sea. The **neritic zone** is a continental shelf, extending outward to its edge to a water depth of about 200m. The open ocean is called the **pelagic zone** and the area underneath the pelagic zone is called the **benthic zone**, or deep-sea. The deepest part of the ocean is called the **abyssal zone**. The pelagic zone which includes all open ocean regions can be subdivided into further regions categorized by light abundance. The photic zone covers the oceans from surface level to 200 metres down. This is the region where the photosynthesis most commonly occurs and therefore contains the largest biodiversity in the ocean.

Hot hydrothermal vents

Hot hydrothermal vents found in the ocean floor, in regions where the ocean floor is spreading and associated with gradual upwelling of mineral-rich fluid from the Earth's interior. Moving Earth's crust creates cracks and crevices in the ocean floor. These cracks allow the sea water to percolate downwards. Sea water that percolates downward is heated and driven back upward, carrying minerals leached from the hot rock. A temperature gradient is set up, from more than 350°C near the core of the vent, down to 2–3°C in the surrounding ocean. Minerals precipitate from the water as it cools, forms a chimney. Different classes of organisms, thriving at different temperatures, live in different neighborhoods of the chimney.

Close to the vent, at temperatures up to about 150°C, various lithotrophic species of eubacteria and archaebacteria live, directly fuelled by geochemical energy. A little further away, where the temperature is lower, various invertebrate animals live by feeding on these microorganisms. The most remarkable are the very large (2 to 3 meters) tube worms, which, rather than feed on the lithotrophic cells, live in symbiosis with them: specialized organs in the worms harbour a huge number of symbiotic sulfur-oxidizing bacteria. These bacteria harness geochemical energy and supply nourishment to their hosts, which have no mouth, gut, or anus.

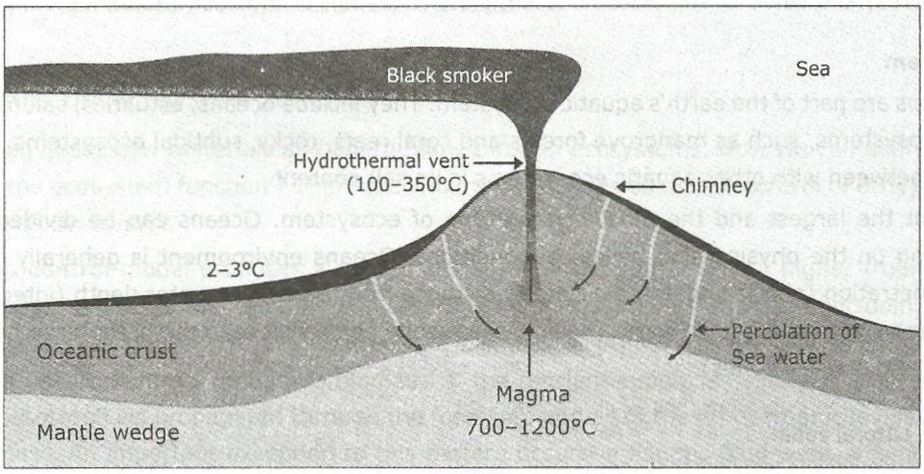


Figure 5.18 A hot hydrothermal vent in the ocean floor. Water percolates down toward the hot molten rock upwelling from the Earth's interior and is heated and driven back upward, carrying minerals leached from the hot rock. A temperature gradient is set up, from more than 350°C near the core of the vent, down to 2–3°C in the surrounding ocean. Minerals precipitate from the water as it cools, forming a chimney. Different classes of organisms, thriving at different temperatures, live in different neighborhoods of the chimney. Close to the vent, at temperatures up to about 150°C, various lithotrophic species of bacteria and archaea (archaebacteria) live, directly fuelled by geochemical energy.

Estuary

An *estuary* (from Latin word means *tide*) is a transition area between river and sea. An estuary begins where fresh river water flows into coastal bays. These areas of transition between the land and the sea are driven by tides, but sheltered from the full force of ocean wind and waves. When fresh water meets salty seawater, both water combines into a *brackish* mixture. At estuary, salinity is intermediate between salt- and fresh water. However, salinity varies spatially within estuaries, from nearly that of fresh water to that of seawater. Salinity also varies with the rise and fall of the tides. Estuaries are often associated with high rates of biological productivity. However, estuaries are not only found where fresh water from rivers and salt water from the ocean meet and mix, but also where fresh water from rivers or streams and chemically distinct water of a large lake meet and mix. These estuaries are called *freshwater estuaries*.

Freshwater ecosystem

Freshwater is so called because of its extremely low salt content. It exists in various forms such as lakes, rivers, ponds or wetlands. The study of the physical, chemical, and biological properties of fresh water is referred to as **limnology**. Freshwater ecosystems are characterized as having running water (*lotic ecosystem*) or still water (*lentic ecosystem*).

Lentic ecosystem such as lakes and ponds like the oceans are divided into separate zones which are defined by their distance from the shore. The **littoral zone**, which is closest to the shore, is host to a wide variety of rooted plants species due to its warm, shallow environment. The **limnetic zone** is the open water farther from shore and dominated by plankton. The deeper region of a lake or pond below the limnetic zone is called the **profundal zone** which contains only heterotrophs. The littoral and limnetic zones have a ratio of $P/R > 1$ (production is greater than respiration) whereas the profundal zone has $P/R < 1$ (respiration is greater than production). The zone at the bottom of a lake or pond is termed **benthic**. The benthic zone is occupied by communities of organisms collectively called the *benthos*. The terms benthic and benthos are derived from the Greek for *depths of the sea*, but the terms are also used in freshwater biology to refer to the zone and organisms at the bottom of freshwater bodies.

Life-forms in a lentic ecosystem include plankton (free-floating organisms), nekton (free–swimming organisms, such as fish), benthos (bottom-dwelling organism), neuston (the collective term for the organisms that float on the top of the water, *epineuston* or live right under the surface, *hyponeuston*), and periphyton (organisms attached to submerged surfaces).

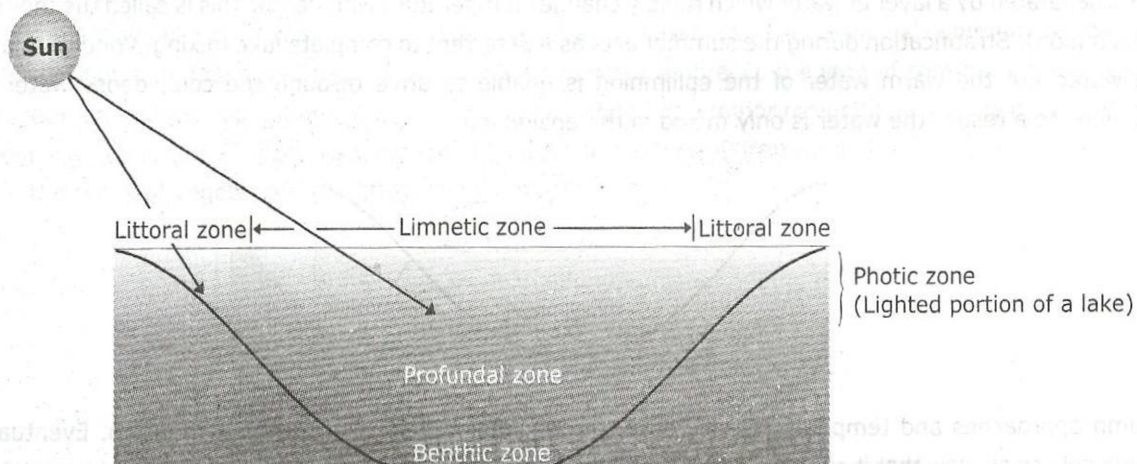
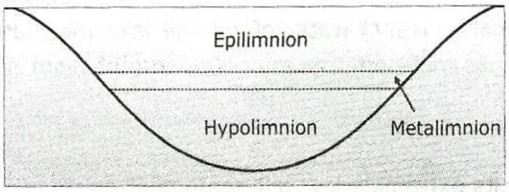


Figure 5.19 The zones in lake water is determined by gradients of light from the water surface to the bottom.

Thermal stratification in lentic ecosystem

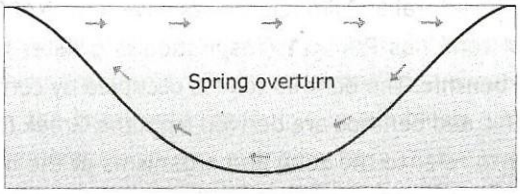
Changes in the temperature profile with depth in an aquatic system are called *thermal stratification*. Fresh water lentic ecosystems such as lakes of temperate regions generally become thermally stratified due to differential heating and cooling. A well stratified lake has a layer of freely circulating warm surface water with small temperature gradient known as the **epilimnion**. A second layer called **metalimnion** (or *thermocline*), which is characterized by a steep decline in temperature, separates the more uniformly warm upper layer from more uniformly cold deeper waters.

The third layer is the **hypolimnion**, a deep, cold layer of dense water where no temperature gradient is evident. *Thermocline checks the mixing of water* between epilimnion and hypolimnion. In fresh water lotic ecosystems, thermal stratification is not observed.



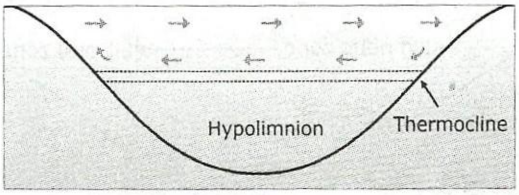
Thermal stratification of lake

Temperature profile changes from one season to the next and creates a cyclical pattern. Let us begin with spring. After the ice melts on a lake, the lake water is generally the same temperature from the surface to the bottom. It allows circulation and mixing of the lake water. Surface water can be pushed to the lake bottom and bottom water can rise to the surface. This circulation pattern allows large amounts of oxygen to reach the bottom of the lake. The mixing of the lake water at this time of year is called *spring overturn*.

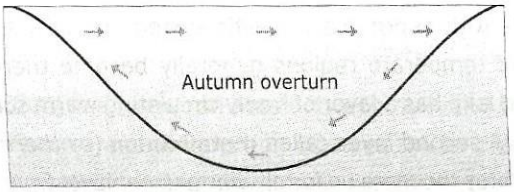


Complete mixing of water, no stratification

As air temperatures rise in summer, heat from the sun begins to warm the lake. The layer of warm water at the surface of the lake is called the epilimnion. The cold layer below the epilimnion is called the hypolimnion. These two layers are separated by a layer of water which rapidly changes temperature with depth. This is called the thermocline (or metalimnion). Stratification during the summer acts as a deterrent to complete lake mixing. Wind circulates the surface water, but the warm water of the epilimnion is unable to drive through the cold, dense water of the hypolimnion. As a result, the water is only mixed in the epilimnion.



As autumn approaches and temperatures decrease, the epilimnion begins to decrease in depth. Eventually the epilimnion gets so shallow that it can no longer be maintained as a separate layer and the lake loses its stratification. Thus, as in the spring, the lake water in the autumn has generally uniform temperatures and wind can once again thoroughly mix the lake water. In addition, surface water, which is in direct contact with the cold air, gets cooled faster than the water below. This cold, dense water sinks and further helps to mix the lake, and once more oxygen and nutrients are replenished throughout the lake. This process is called *autumn overturn*.



Complete mixing of water, no stratification

As winter approaches, the surface water is eventually cooled below 4°C. As water temperature at the surface reach 0°C, ice begins to cover the surface of the lake. During the winter, ice cover prevents wind from mixing the lake water. Again, stratification can occur. A layer of water colder than 4°C, but warmer than 0°C forms just under the ice. Below this water, the remainder of lake water is usually near 4°C.

Wetlands

Wetlands are ecosystems in which the land surface is saturated or covered with standing water either permanently or seasonally. The water found in wetlands can be saltwater, freshwater or brackish. Brackish water has more salinity than freshwater, but not as much as sea water.

Three major features used to describe the wetlands are hydrology or wetness, type of vegetation and type of soil. The major types of wetlands are: *marsh*, *swamp*, *bogs* and *fen*.

Marshes are the most productive wetlands characterized by mineral soils, and are typically dominated by grasses and floating-leaved plants. *Swamps* are forested wetlands characterized by mineral soil, seasonally or permanently flooded, and dominated by trees. Thus, grasses dominate *marshes*, while trees dominate *swamps*.

Bogs and fens are organic soil wetlands. Organic soil is produced by the accumulation of plant materials. Generally these wetlands are referred to as *peatlands* due to their ability to form peat. Bogs are acidic, unproductive wetlands that develop in relatively cool but wet climates. Bogs receive water exclusively from rain fall and depend on atmospheric inputs for their supply of nutrients, and are typically dominated by species of moss. *Fens* are alkaline rather than acid areas, receiving water mostly from surface and ground water sources.

Terrestrial Ecosystems

Terrestrial ecosystems are land based ecosystems such as forest, desert, grassland, etc. Terrestrial ecosystems can be grouped into units of similar nature called biomes which are discussed as

5.8 Biomes

The biome concept was introduced by Clements and Shelford. A distinct ecological community of plants and animals living together in a particular climate is called a *biome*. It is a level of organization between the landscape and biosphere. It is the largest geographical biotic unit, and is named after the dominant type of life form, such as tropical rain forest and grassland.

A biome is composed *not* only of the climax vegetation, but also of associated successional communities, persistent subclimax communities, fauna and soil. Thus, the biome concept embraces the idea of community, of interaction among vegetation, animal populations, and soil. It may be defined as a major region of distinctive plant and animal groups well adapted to the physical environment of its distribution area. Differences in temperature or precipitation determine the types of vegetation that grow in a given area.

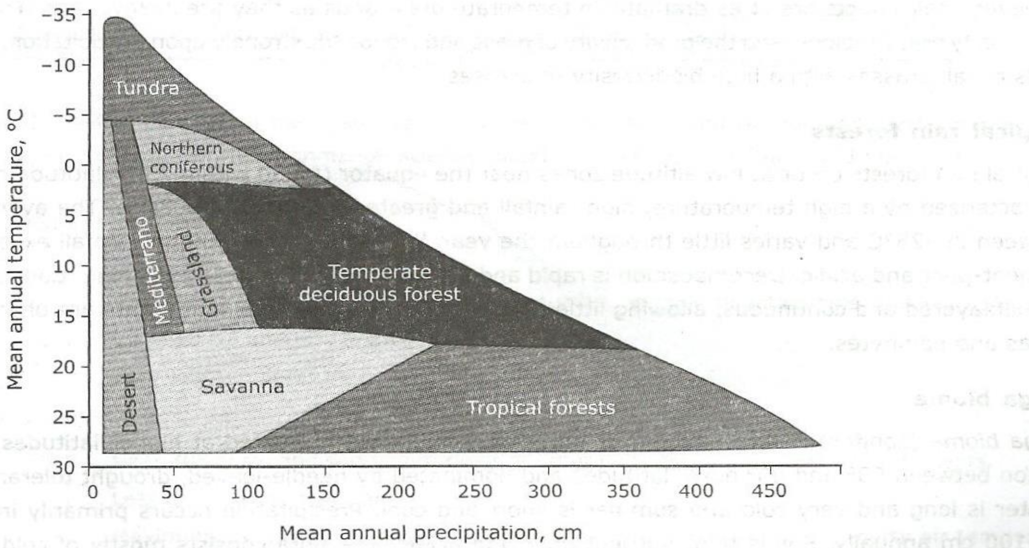


Figure 5.20 The distribution of vegetation types as a function of mean annual temperature and precipitation.

Biomes are classified into aquatic and terrestrial biomes. Some of the major terrestrial biomes in the world are tropical rain forests, deserts, tropical grasslands (savannas), temperate grasslands, temperate deciduous forests, Mediterranean scrub, coniferous forests, chaparral and tundra.

Tundra biome

Tundra is a polar desert, with very low temperature and low precipitation. There are two main types of tundra, *arctic tundra* and *alpine tundra*. The alpine tundra is found high on the mountains. Tundra biome is characterized by a short growing season, low precipitation and permanently frozen deeper soil (called *permafrost*). Plant life consists of grasses, sedges and lichen (Reindeer moss). Trees are absent.

Desert biome

Deserts are found at latitudinal positions between 15° to 35° North and South of the equator and also in rain shadows. Deserts have annual precipitation less than 30 cm. Low precipitation may be due to high subtropical pressure, geographical position in a rain shadow and high elevation. There is a lot of variability in desert types, with hot deserts, cold deserts, high elevation deserts, and rain shadow deserts. Consequently, there is a great deal of variation in the biodiversity, productivity and organisms found in different types of desert. Most deserts are very hot. The hot deserts generally experience hot days and cold nights. Three types of plant forms are adapted to deserts - ephemeral, succulent and non-succulent.

Tropical grassland (or Savanna biome)

Savanna is grassland with *scattered* individual trees. Climate is the most important factor in creating a savanna. Savannas which result from climatic conditions are called *climatic savannas* (savannas that are caused by soil conditions are called *edaphic savannas)*.

Savannas are always found in warm or hot climates where the annual rainfall is between 30–50 cm per year. The soils are porous, having only a thin layer of nutrient rich matter called humus. Three major selective forces dominate the evolution of plant traits in savannas - recurring fire, periodic drought, and grazing. There are frequent fires in the savanna and the dominant vegetation is fire-adapted.

Temperate grasslands

Temperate grasslands are characterized as having grasses as the dominant vegetation. Trees and large shrubs are absent. Temperate grasslands have hot summers and cold winters and the amount of rainfall is less than in savannas. As in the savanna, seasonal drought and occasional fires are very important to maintain biodiversity. However, their effects aren't as dramatic in temperate grasslands as they are in savannas. The type of grassland community that develops, and the productivity of grasslands, depends strongly upon precipitation. Higher precipitation leads to tall grasses with a high biodiversity of grasses.

Tropical rain forests

Tropical rain forests occur at low altitude zones near the equator (found within 23.5° latitude of the equator), and characterized by a high temperature, high rainfall and greatest diversity of species. The average temperature is between 20–25°C and varies little throughout the year. Winter is absent. Annual rainfall exceeds 200 cm. Soil is nutrient-poor and acidic. Decomposition is rapid and soils are subject to heavy leaching. Canopy in tropical forests is multilayered and continuous, allowing little light penetration. The dominant plants are phanerophytes – trees, lianas and epiphytes.

Taiga biome

Taiga biome (coniferous forest biome or boreal forest biome) is located at higher latitudes, close to the polar region between 50° and 60° north latitudes and dominated by needle-leaved, drought tolerant, evergreen trees. Winter is long and very cold and summer is short and cool. Precipitation occurs primarily in the form of snow, 40–100 cm annually. Soil is thin, nutrient-poor and acidic. The flora consists mostly of cold-tolerant evergreen conifers with needle-like leaves, such as pine, fir and spruce. *Taiga* is the largest terrestrial biome on Earth.

Temperate deciduous forest biome

A temperate deciduous forest consists of trees that lose their leaves every year. The temperate deciduous forest has a temperate climate, with moderate temperatures that have a distinct seasonal pattern. Temperate climate has four seasons of winter, spring, summer and fall. Precipitation (65 to 130 cm) is distributed evenly throughout the year. Soil is fertile, enriched with decaying litter.

Chaparral biome

Chaparral is the name applied to the evergreen sclerophyllous (hard-leaved) shrub vegetation. Chaparral biome is a scrubland biome of dense, spiny evergreen shrubs found at mid-latitudes along coasts where cold ocean currents circulate offshore. Chaparral biome is characterized by mild, rainy winters and long, hot, dry summers. Annual precipitation generally falls within the range of 30–50 cm.

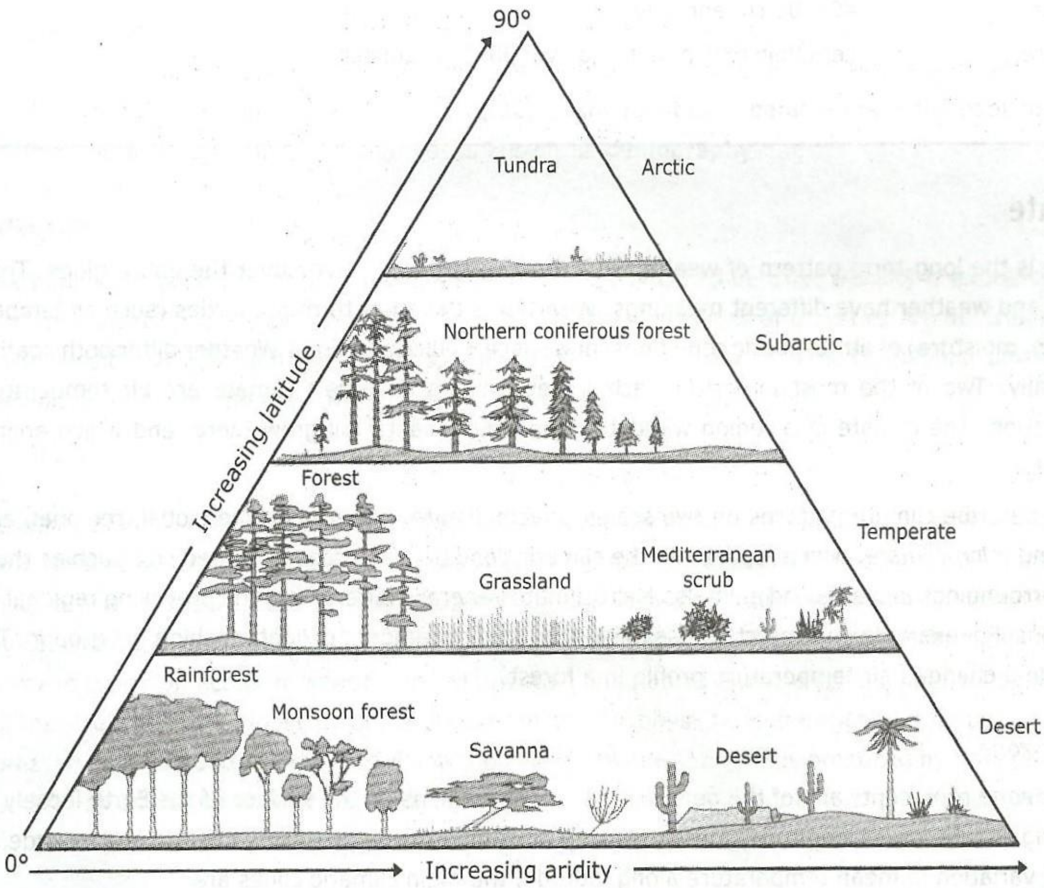


Figure 5.21 Simplified diagram of the relationship between precipitation and latitude and Earth's major land biomes. Adapted from Environmental science, Botkin and Keller, John Wiley and Son. Inc.

Table 5.3 General features of some terrestrial biomes.

Tundra biome		
Distribution	:	Arctic tundra, in arctic region and alpine tundra, on high mountain tops at all latitudes.
Precipitation	:	20 to 60 cm annually in arctic tundra.
Temperature	:	Very low temperature.
Desert biome		
Distribution	:	Near 30° north and south latitude or at other latitudes in the interior of continents.
Precipitation	:	Less than 30 cm per year.
Temperature	:	Maximum temperature in hot deserts may exceed 50°C; in cold deserts air temperature

Savanna biome

Distribution	:	Equatorial and subequatorial regions.
Precipitation	:	Average 30–50 cm annually.
Temperature	:	Average 24–29°C.

Tropical rain forests

Distribution	:	Equatorial and subequatorial regions.
Precipitation	:	About 200–400 cm annually.
Temperature	:	Average 25–29°C

Taiga biome

Distribution	:	50 and 60° North latitudes.
Precipitation	:	40–100 cm annually.
Temperature	:	Less than 0°C in winter to over 30°C in summer.

1.2 ENERGY FLOW IN AN ECOSYSTEM

5.7.4 Energy flow

Energy flow is the key function in the ecosystem. The storage and expenditure of the energy in the ecosystem is based on two basic laws of thermodynamics. The *first law of thermodynamics* states that when energy is converted from one form into another, energy is neither gained nor lost. The first law is also called the *law of conservation of energy*. The *second law of thermodynamics* states that every transformation results in a reduction of the free energy of the system. Energy transformation cannot be 100% efficient (second law).

The operation of an ecosystem, is consistent with the laws of thermodynamics that deal with the relationships between energy and matter in a system. First, we can account for the total energy input to an ecosystem in budgetary fashion. This is consistent with the first law of thermodynamics.

Energy may change form (e.g. from radiant to chemical) but not amount. But as the energy moves through an ecosystem, it does change form, ultimately to heat, which is not directly usable by the system. Thus the system tends to run down, dissipating its energy and losing its organized structure. This is the nature of the second law of thermodynamics, a tendency toward maximum disorganization of structures and maximum dissipation of usable energy.

General principles of energy flow

The behaviour of energy in ecosystems is referred to as *energy flow* because energy transformations are directional, in contrast to the cyclical behaviour of nutrients. The conversion of solar radiation to chemical energy by photosynthesis is the starting point of energy flow within ecosystems.

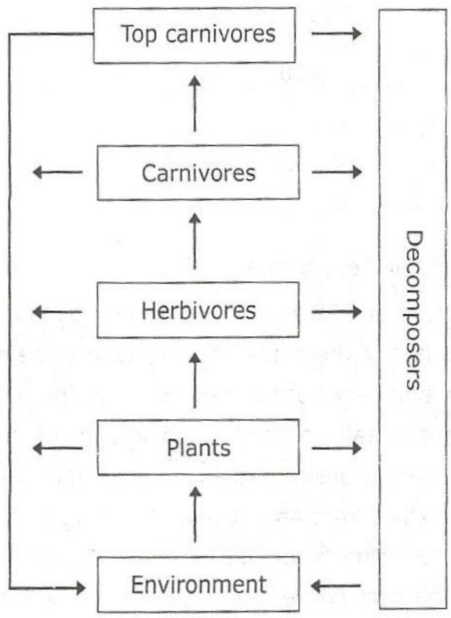
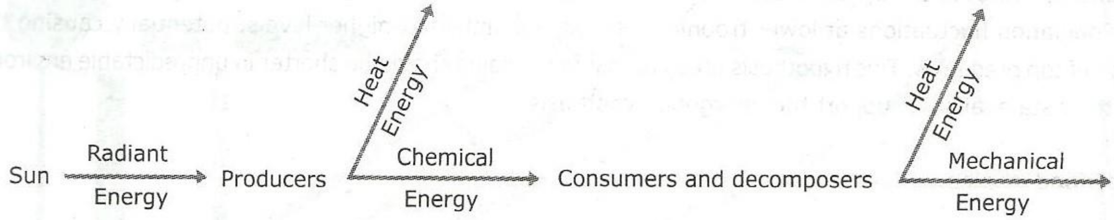


Figure 5.5 Energy pathways through an ecosystem. Usable energy flows from the external environment to the plants, then to the herbivores, carnivores, and top carnivores. Death at each level transfers energy to decomposers. Energy lost as heat is returned to the external environment. Adapted from Environmental science, Botkin and Keller, John Wiley and Son. Inc.

Solar energy is transformed from the radiant to the chemical form in photosynthesis and from the chemical to mechanical and heat forms in cellular metabolism. These conversions and sequences are fundamental to the energetics of organisms and ecosystems as energy passes into and through producers, to and through consumers and decomposers.



Only about 1–5 percent energy of incident radiation, or 2–10 percent of PAR (Photosynthetically Active Radiation) is actually captured by the photosynthetic process (gross primary productivity), and the remaining portion is dissipated. Since the simultaneously occurring respiratory processes are energy consuming and use up part of the photosynthetic gain, the net capture of energy (net primary productivity is reduced to only 0.8–4 percent of the incident total radiation, or 1.6–8 percent of PAR. Only the energy captured in net productivity of producers can be used by other trophic levels.

Autotroph and detritus-based ecosystem

The *autotroph based ecosystems* depend directly on the influx of solar radiation. They are characterized by a dependence on energy capture by photosynthetic autotrophs and secondarily by the movement of the captured energy through the system via herbivory and carnivory. A large number of ecosystems function in this way and numerous herbivores, carnivores and omnivores are dependent on such autotrophic ecosystems.

Some ecosystems depend less on direct solar energy incorporation and more on the influx of dead organic material, or detritus, produced in another ecosystem. Ecosystems, such as caves, are completely independent of direct solar energy and are instead completely energy dependent on the influx of detritus. These entities can be regarded as *detritus-based ecosystems*.

Autochthonous and Allochthonous

All biotic communities depend on a supply of organic matter (i.e. energy) for their activities. In most terrestrial ecosystems, organic matters are produced by photosynthesis within an ecosystem's boundaries – this is known as *autochthonous* production.

However, an ecosystem can receive organic matter from sources other than its own photosynthesis – via the import of dead organic matters that has been produced elsewhere. Organic matter imported from elsewhere is called *allochthonous*.

5.7.5 Food chains

A classic paper by Lindeman (1942) laid the foundations of ecological energetics. He attempted to quantify the concept of food chains and food webs by considering the efficiency of transfer between trophic levels – from incident radiation received by a community through its capture by green plants in photosynthesis to its subsequent use by herbivores, carnivores and decomposers.

A characteristic of an ecosystem is the number and nature of the species that occupy its various trophic levels. The relationship between constituents of one trophic level and constituents of adjacent trophic levels may be described by a food chain. A *food chain* shows the movement of energy through a system by indicating the path of food from a producer to a final consumer. In general, food chains have 3 to 5 trophic links with 15 to 20 species. The length of food chain also may reflect the physical characteristics of a particular ecosystem. A harsh arctic landscape has a much shorter food chain than a temperate or tropical one.

Why are food chains relatively short? There are two main hypotheses. One, the *energetic hypothesis*, suggests that the length of a food chain is limited by the inefficiency of energy transfer along the chain. As we know, only about 10% of the energy stored in the organic matter of each trophic level is converted to organic matter at the next trophic level.

The second hypothesis, the *dynamic stability hypothesis*, proposes that long food chains are less stable than short chains. Population fluctuations at lower trophic levels are magnified at higher levels, potentially causing the local extinction of top predators. This hypothesis predicts that food chains should be shorter in unpredictable environments. Most of the data available support the energetic hypothesis.

Types of food chains

Grazing food chains

Grazing food chains derive their energy directly from the sun. The grazing food chain begins with primary producers. Primary consumers or herbivores form the second link in the grazing food chain. They gain their energy by consuming primary producers. Secondary consumers or primary carnivores, the third link in the chain, gain their energy by consuming herbivores. Tertiary consumers or secondary carnivores are animals that receive their organic energy by consuming primary carnivores.

Autotroph → Herbivore → Primary Carnivore → Secondary Carnivore

Detritus food chains

Detritus food chains begin with dead organic matter which is an important source of energy. A large amount of organic matter is contributed by the death of plant's parts, animals and their excretion products. These types of food chains are present in all ecosystems. Various species of microscopic fungi, bacteria and other saprophytes play a prominent role in decomposing organic matter to obtain energy needed for their survival and growth.

Detritus food chains are connected to a grazing food chain. Most of the natural ecosystems possess both grazing and detritus types of food chains. Their relative importance, however, varies from one ecosystem to another. In terrestrial and shallow water ecosystems, grazing food chains dominate because a major proportion of the annual energy flow passes through this circuit. In case of tidal marshes, almost 90% of the primary production is routed through the detritus food chains.

Food web

More often than not, such simple food chains are oversimplified versions of the reality of feeding relationships. Instead, there are often multiple and interconnecting pathways, as well as numbers of different species involved at each trophic level. These complex pathways resemble a web rather than a simple chain and are referred to as *food webs*. So, a food web is a pictorial representation of the feeding relationship between organisms in an ecosystem and consists of interlocking food chains.

5.7.6 Energy flow model

A simplified representation of energy flow through ecosystem has been made in figure 5.6. The model attempts to recognize the various inputs and fates of energy. Two aspects with respect to energy flow in the ecosystem need careful consideration. First, the energy flows one way, i.e., from producers through herbivores to carnivores; it cannot be transferred in the reverse direction. Second, the amount of energy flow decreases with successive trophic levels.

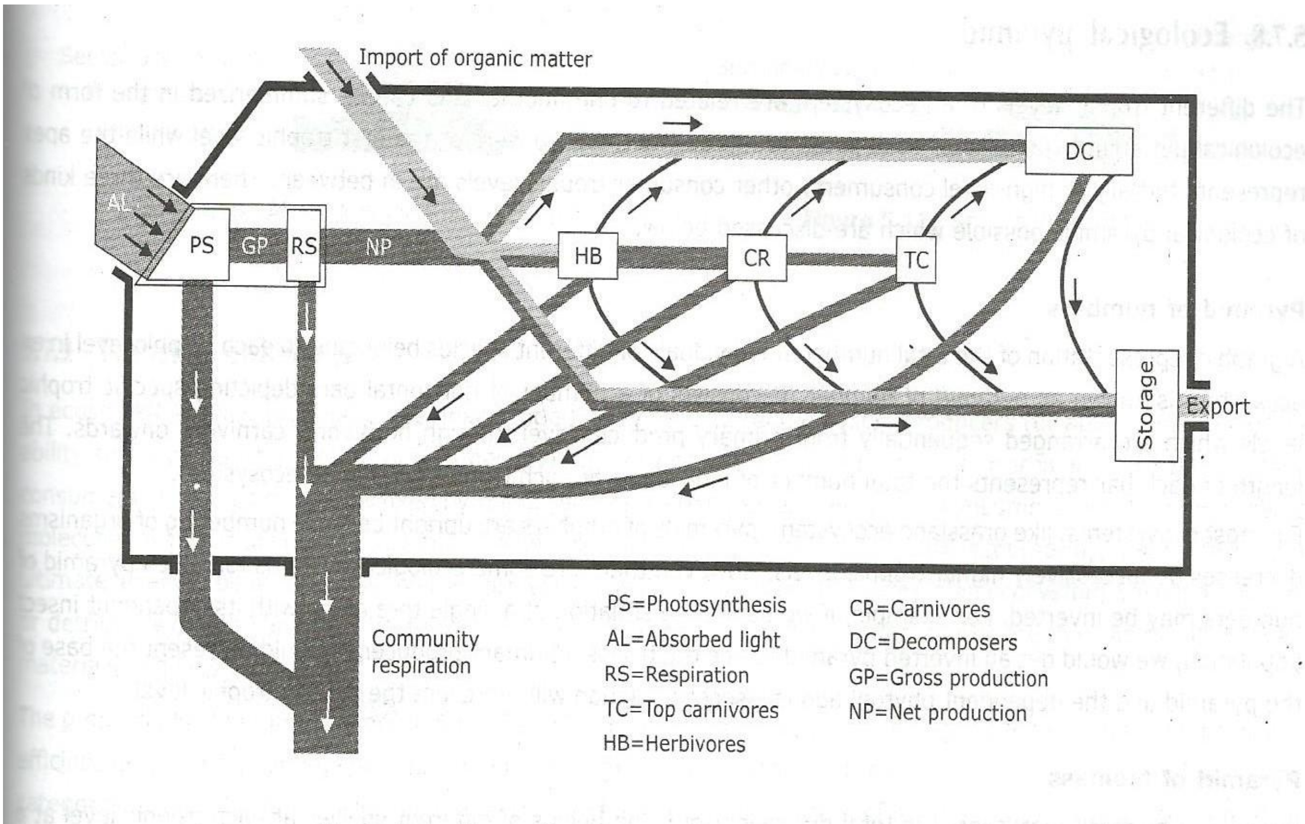


Figure 5.6 Energy flow diagram of a generalized ecosystem.

4.3 BIOGEOCHEMICAL CYCLES

A biogeochemical cycle is one of several natural cycles, in which conserved matter moves through the biotic and abiotic parts of an ecosystem.

In biology, conserved matter refers to the finite amount of matter, in the form of atoms, that is present within the Earth. Since, according to the Law of Conservation of Mass, matter cannot be created or destroyed, all atoms of matter are cycled through Earth's systems albeit in various forms.

In other words, the Earth only receives energy from the sun, which is given off as heat, whilst all other chemical elements remain within a closed system.

The main chemical elements that are cycled are: carbon (C), hydrogen (H), nitrogen (N), oxygen (O), phosphorous (P) and sulfur (S).

5.7.10 Nutrient cycling

As the earth is essentially a closed system with respect to matter, we can say that *all matter on earth cycles*. Every matter that is used by living organisms passes between the biotic and abiotic components of the biosphere. *Nutrient cycling* is the movement (or cycling) of matter through the system. In general, we can subdivide the system into: atmosphere, hydrosphere, lithosphere and biosphere. By matter we mean elements (such as carbon, nitrogen, oxygen) or molecules (water). The movement of matter between these parts of the system is generally termed as a *biogeochemical cycle*.

Gaseous and sedimentary nutrient cycles

In *gaseous nutrient* cycles, the atmosphere constitutes a major reservoir of the element that exists in a gaseous phase. Such cycles show little or no permanent change in the distribution and abundance of the element. Carbon and nitrogen are prime representatives of biogeochemical cycles with a prominent gaseous phase.

In a *sedimentary cycle,* the major reservoir is the lithosphere from which the elements are released largely by weathering. The sedimentary cycles, exemplified by phosphorus, sulfur, iodine, and most of the other biologically important elements, have a tendency to stagnate. In such cycles, a portion of the supply may accumulate in large quantities, as in the deep ocean sediment, and thereby become inaccessible to organisms and to continual cycling. Some of the elements that are characterized by sedimentary cycles do have a gaseous phase, sulfur and iodine being among them, but these phases are insignificant in that there is no large gaseous reservoir.

Global and local nutrient cycles

An element's specific route through a biogeochemical cycle varies with the particular element and the trophic structure of the ecosystem. There are, however, two general categories of biogeochemical cycles: global and local. Gaseous forms of carbon, oxygen, sulfur and nitrogen occur in the atmosphere, and cycles of these elements are essentially global. Other, less mobile elements, including phosphorus, potassium and calcium, generally cycle on a more localized scale, at least over the short term. Soil is the main abiotic reservoir of these elements.

General model of nutrient cycling

A general model of nutrient cycling includes the main reservoirs of elements and the processes that transfer elements between reservoirs. Each reservoir is defined by two characteristics: whether it contains organic or inorganic materials and whether or not the materials are directly available for use by organisms. The nutrients in living organisms and in detritus are available to other organisms when consumers feed and when detritivores consume nonliving organic matter. Some materials are moved from the living or organic reservoir to the fossilized organic reservoir, when dead organisms were buried by sedimentation over millions of years, becoming coal, peat. The nutrients in these deposits cannot be assimilated directly.

Inorganic materials (elements and compounds) that are dissolved in water or present in the soil or air are available for use. Organisms assimilate materials from this reservoir directly and return chemicals to it through the relatively rapid processes of cellular respiration, excretion and decomposition. Although organisms cannot directly tap into the inorganic elements tied up in the rocks, these nutrients may slowly become available through weathering and erosion. Similarly, unavailable organic materials move into the available reservoir of inorganic nutrients when fossil fuels are burned, releasing exhaust into the atmosphere.

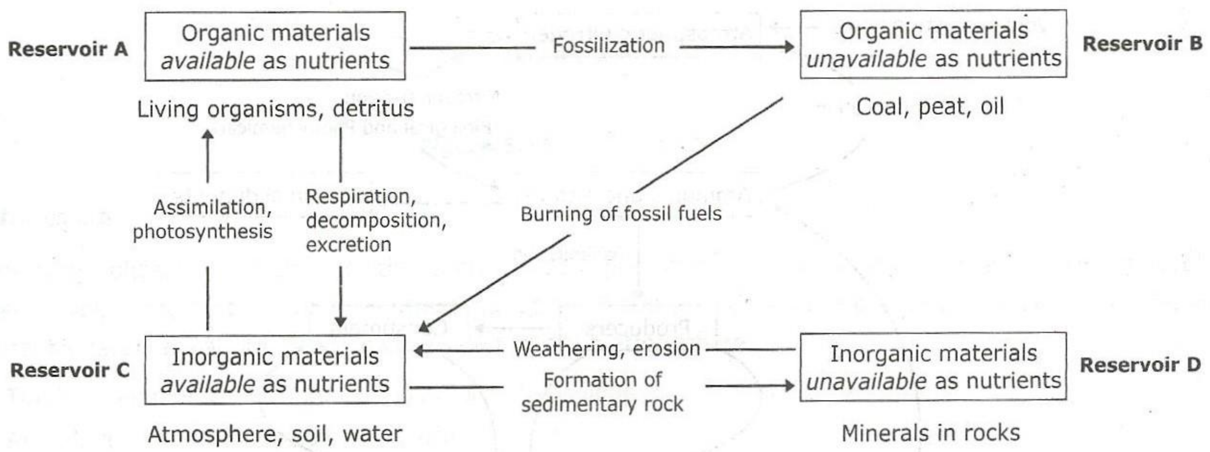


Figure 5.12 A general model of nutrient cycling.

Carbon cycle

Photosynthesis and respiration are the two opposing processes that drive the global carbon cycle. It is predominantly a gaseous cycle, with CO_2 as the main vehicle of flux between the atmosphere, hydrosphere and biota. Terrestrial plants use atmospheric CO_2 as their carbon source for photosynthesis, whereas aquatic plants use dissolved carbonates (i.e. carbon from the hydrosphere).

In addition, carbon finds its way into inland waters and oceans as bicarbonate resulting from the weathering of calcium-rich rocks such as limestone and chalk. Respiration by plants, animals and microorganisms releases the carbon locked in photosynthetic products back to the atmospheric and hydrospheric carbon compartments.

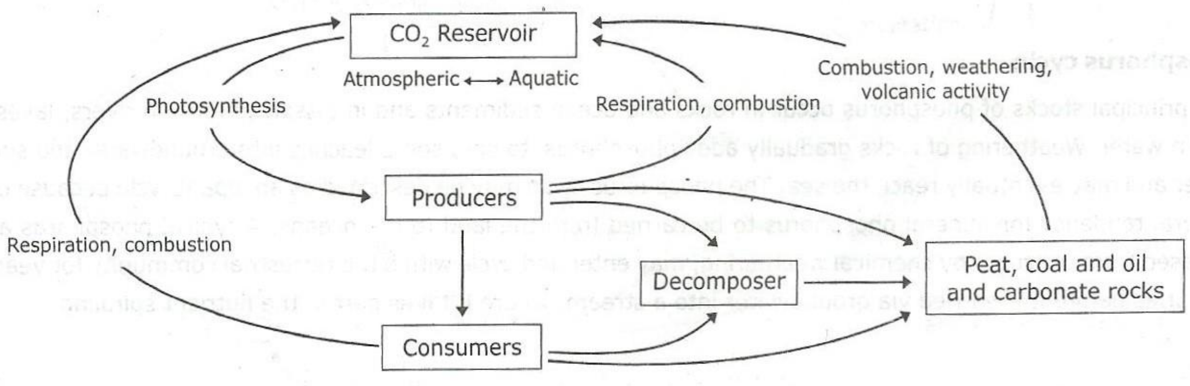


Figure 5.13 Carbon cycle

Nitrogen cycle

The atmospheric phase is predominant in the global nitrogen cycle. In nitrogen cycle, nitrogen is converted between its various chemical forms. This transformation can be carried out by both biological and non-biological processes. The important processes in the nitrogen cycle include nitrogen fixation, ammonification, nitrification, and denitrification. *Nitrogen fixation* involves the conversion of N_2 by bacteria to ammonium ions. Atmospheric nitrogen is also fixed by lightning discharges during storms and reaches the ground as nitric acid dissolved in rainwater, but only about 3–4% of fixed nitrogen derives from this pathway. *Ammonification* involves decomposition of organic nitrogen to ammonium ions. In *nitrification*, ammonium ion is converted to nitrite and nitrate by nitrifying bacteria. *Denitrification* is the reduction of nitrates into nitrogen gas. This process is performed by bacterial species such as *Pseudomonas* and *Clostridium* in anaerobic conditions.

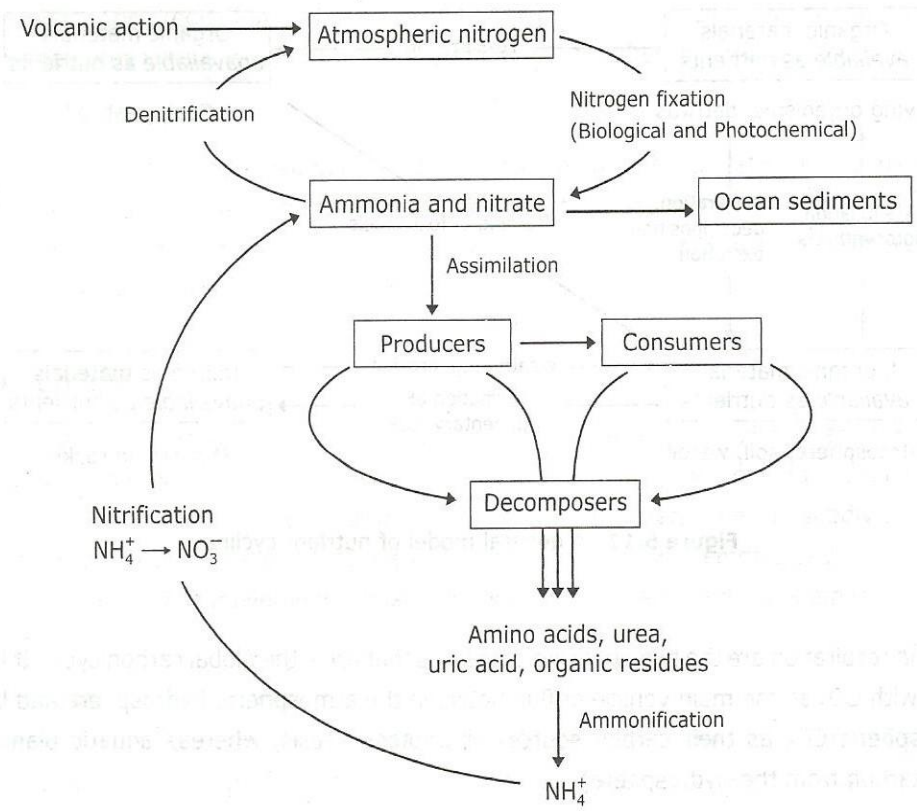


Figure 5.14 Nitrogen cycle.

Phosphorus cycle

The principal stocks of phosphorus occur in rocks and ocean sediments and in dissolved form in rivers, lakes and ocean water. Weathering of rocks gradually adds phosphorus to soil; some leaches into groundwater and surface water and may eventually reach the sea. The phosphorus cycle may be described as an 'open' cycle because of the general tendency for mineral phosphorus to be carried from the land to the oceans. A typical phosphorus atom, released from the rocks by chemical weathering, may enter and cycle within the terrestrial community for years, or centuries before it is carried via groundwater into a stream, where it takes part in the nutrient spiraling.

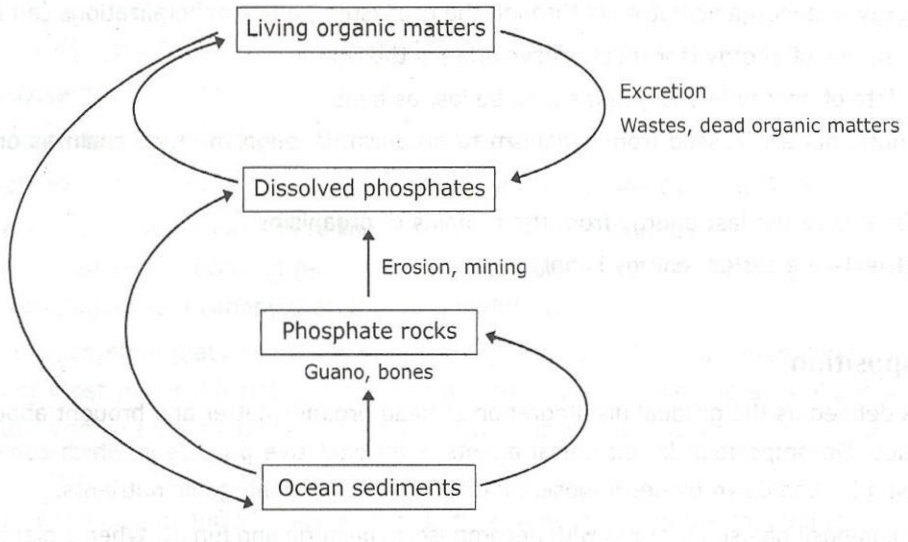


Figure 5.15 Phosphorous cycle.

Sulfur cycle

In the global phosphorus cycle, the lithospheric phase is predominant, whereas in the nitrogen cycle, atmospheric phase is more important. Sulfur, by contrast, has atmospheric and lithospheric phases of similar magnitude. Three natural biogeochemical processes release sulfur into the atmosphere:

- The formation of the volatile compound dimethylsulfide
- Anaerobic respiration by sulfate-reducing bacteria; and
- Volcanic activity.

The weathering of rocks provides about half the sulfur draining off the land into rivers and lakes, the remainder deriving from atmospheric sources. The available sulfur taken up by plants, passed along food chains and, via decomposition processes, becomes available again to the plants. The combustion of fossil fuels is the major human activity to the global sulfur cycle.

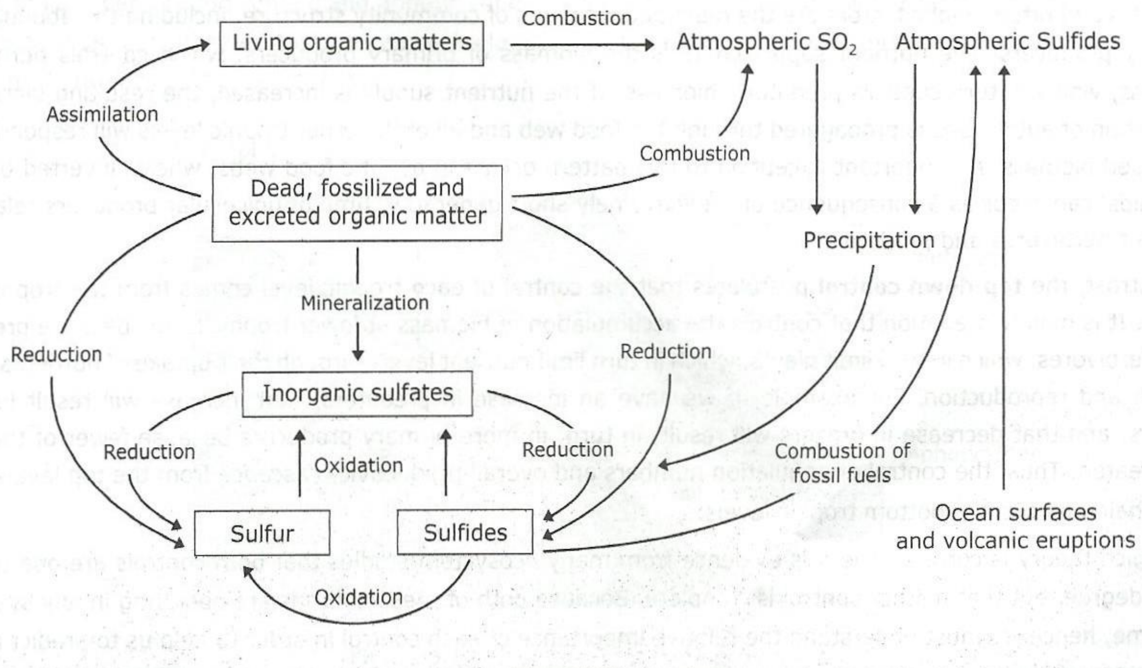


Figure 5.16 Sulfur cycle.

3.4 POPULATION CHARACTERISTICS

5.9 Population ecology

A *population* is a collection of individuals of the same species that live together in a region. *Population ecology* is the study of populations (especially population abundance) and how they change over time. It studies the spatial and temporal patterns in the abundance and distribution of organisms and of the mechanisms that produce those patterns. The aims of population ecology are threefold: 1. to elucidate general principles explaining these dynamic patterns; 2. to integrate these principles with mechanistic models and evolutionary interpretations of individual life-history tactics, physiology, and behaviour as well as with theories of community and ecosystem dynamics; and 3. to apply these principles to the management and conservation of natural populations.

5.9.1 Population characteristics

A population has several characteristics or attributes which is a function of the whole group and not of the individual. Different populations can be compared by measuring these attributes. These attributes are population density, natality, mortality, growth forms, etc. The study of the group characteristics or parameters of the population, their changes over time and prediction of future changes is known as **demography**.

Population density

The size of the population is represented by its fundamental property called *density*. Density is expressed as the total number of individuals per unit area or volume at a given time. Two types of densities are described - **crude density** (it is the density per unit total space) and **specific** (ecological) **density** (it is the density per unit of habitat space i.e. available area or volume that can actually be colonized by the population).

Natality

Natality is the ability of individuals of a population to produce new individuals. The natality rate is equivalent to the birth rate in the terminology of human population study (demography). Maximum (sometimes called *absolute* or *physiological*) natality is the theoretical maximum production of new individuals under ideal environmental conditions (i.e. no ecological limiting factors) and is a constant for a given population. *Ecological* or *realized* natality refers to population increase under an actual or specific environmental condition. It is not a constant for a population but may vary with the size and age composition of the population and the physical environmental conditions. Natality is generally expressed as a rate determined by dividing the number of new individuals produced by time (*absolute* or *crude natality rate*) or as the number of new individuals per unit of time and per unit of population (the *specific natality rate*).

Mortality

Mortality refers to the death of individuals in the population. It is equivalent to the death rate in human demography. Like natality, mortality may be expressed as the number of individuals dying in a given period.

Ecological or *realized* mortality is the loss of individuals, under a given environmental condition. Like ecological natality, it is not a constant but varies with population and environmental conditions. A theoretical *minimum mortality*, a constant for a population, represents the loss under ideal or non-limiting conditions. Information of the death and survivor of a population with respect to age is represented in the form of table known as **life table**.

What is really vital for the population is not which members die, but which member survives? Consequently specific mortality rate of a population is expressed by survivorship curve. **Survivorship curves** plot the number of surviving individuals to a particular age. Survivorship curves are of three general types:

A *highly convex curve* (type I) is characteristic of the species in which the population mortality rate is low until near the end of the life span. Many species of large animals such as deer, mountain sheep and man, show such curves.

A *highly concave curve* (type III) is characteristic of those species where the mortality rate is high during the young stages. Oysters or shell fish show this type of curve. In oysters mortality is extremely high during free swimming larval stages, but once an individual is well established on a favourable substrate, life expectancy improves considerably.

In *type II curve* which falls between type I and III, the rate of mortality is constant at all age groups, so that an individual's chance of living another year is just as good at one age as another. This curve is typical of several birds and of human beings exposed to poor nutrition and hygiene.

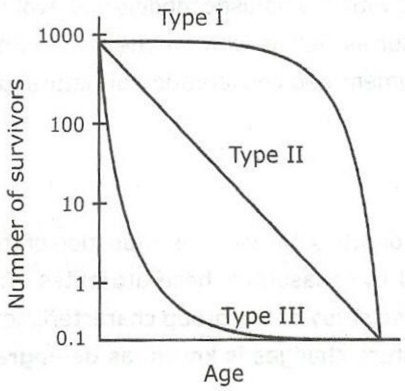


Figure 5.22 Three main types of survivorship curves.

Type I a convex curve in which mortality is low initially and most of the mortality occurs towards the end of the life.

Type II a straight line in which mortality is more or less constant throughout the life span.

Type III a concave curve in which mortality is extremely high initially but decreases markedly for much of the remainder of the life span.

Type I survivorship curves are typical of organisms which are likely to breed several times during the course of their life span. This strategy is referred to as *iteroparous.* Species with a type III curve are more likely to breed only once during their lifetime, a strategy referred to as *semelparous.* Note that the terms *semelparous* and *annual* are not strictly synonymous. *Semelparous* refers to the type of reproductive event, whereas *annual* refers to the life span. Similarly, the term perennial refers to organisms (most often plants) that live for more than one year, whereas *iteroparous* refers to the number of reproductive events in the life span. In plants, the terms *monocarpy* and *polycarpy* are sometimes used instead of semelparity and iteroparity.

The three survivorship curves are generalizations, and few population exactly fit one of the three. Some species have one type of survivorship curve early in life and another type as adults. Herring gulls have a type III survivorship curve early in life and type II curve as adults.

Dispersion

Dispersion refers to the spatial and temporal distribution pattern of individuals of a population. Individuals in a population may be distributed in three broad patterns – Regular, Random and Clumped (aggregated or contagious).

In the case of *regular dispersion,* the individuals are more or less spaced at equal distance from one another. This is rare in nature but is common in managed systems like croplands.

In *random dispersion,* the position of one individual is unrelated to the positions of its neighbours. This kind of distribution occurs where the environment is very uniform and there is no tendency to aggregate. This is also relatively rare in nature.

In *clumped dispersion* (most populations exhibit this kind of dispersion) individuals are aggregated into groups of varying size.

Age structure

It is obvious that individuals in a population will be of different age groups. Relative numbers of young and old individuals in a population will significantly influence the behaviour of a population such as natality and mortality.

The proportion of individuals in each age group is called the *age structure* of that population. A group of individuals which are all roughly of same age is called a *cohort*. Age distribution influences both natality and mortality of the population. The ratio of various age groups in a population determines the current reproductive status of the population.

The age structure of any population can be classified into three categories, i.e. *Pre-reproductive*, Reproductive and Post-reproductive ages. The relative duration of these age groups in proportion to the life span varies greatly with different organisms. In man, the three ages are relatively equal in length.

Age pyramids

The easiest and most convenient way to represent the age distribution in a population is to arrange the data in the form of age pyramid. An *age pyramid* is a vertical bar graph which represents the number or proportion of individuals in various age groups at any given time i.e. age pyramid is the model representing geometrically the proportions of different age groups in the populations of any organisms. There are three types of hypothetical age pyramids:

Expanding population

In a rapidly growing population birth rate is high and population growth may be exponential, as in the case of the housefly, yeast and alga. Under these conditions each successive generation will be more numerous than the preceding one; as a result, a *pyramid-shaped* age structure results.

Stable population

As the rate of growth decreases and stabilizes, the pre-reproductive and reproductive age groups become more or less equal in size; the post-reproductive groups, remains as the smallest. The graphic representation of this stabilized population is *bell-shaped*.

Diminishing population

If the birth rate is drastically reduced, the pre-reproductive group dwindles in proportion to the reproductive and post-reproductive groups, resulting in an *urn-shaped* age structure. This is representative of a population that is dying off.

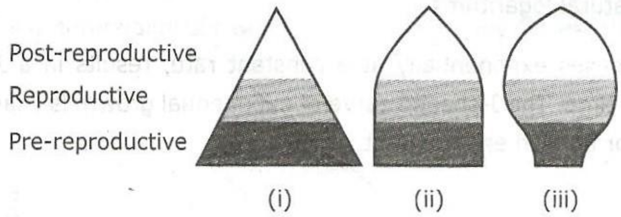


Figure 5.23 Age structure of different types of populations: (i) expanding population (indicating a high percentage of young individuals in a population) (ii) stable population (indicating moderate proportion of young to old individuals) (iii) diminishing population (indicating a low number of young individuals).

Population dispersal

A population is inherently dynamic in nature since individuals are always leaving or entering the populations. But such changes normally do not affect the size of a population. Population dispersal is the movement of individuals into or out of the population or the population area. It occurs in three following ways–

Emigration – one way outward movement of individuals from an area.

Immigration – one way inward movement of individuals into an area.

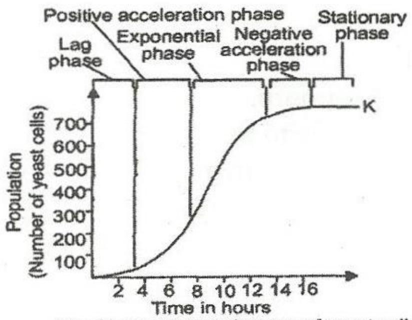
Migration – periodic departure and return of individuals to the same area.

Population Growth Forms

Populations have characteristic patterns of increase which are called population growth forms. Such growth forms represent the interaction of biotic potential and environmental resistance. Two basic patterns of **population growth forms** based on the shape of growth curve are S-shaped and J-shaped growth curve.

S-shaped or sigmoid or logistic growth curve

This type of growth curve is shown by the yeast cells grown under laboratory conditions. It is also shown by the populations of most organisms. It has 5 phases: lag phase, positive acceleration phase, exponential phase, negative acceleration phase, and stationary phase.



The S-shaped growth curve of yeast cells

Lag phase: In the beginning, the small population of yeast cells adapts itself to the new environment. There is little or no increase in population.

Positive acceleration phase: Increase in population starts and occurs at a slow rate in the beginning.

Exponential phase Increase in population becomes rapid and soon attains its fall potential rate. This is due to the constant environment, to the availability of food and other requirements of life in plenty to no predation and interspecific competition, and to no serious intraspecific competition so that the curve rises steeply upward.

Negative acceleration phase: The growth rate finally slows down as environmental resistance increases. Environmental resistance is due to many factors such as more competition for food, less space, and greater mortality.

Stationary phase: Finally, the population becomes stable because now the number of new cells produced, almost equals the number of cells that die. Every population tends to reach a number at which it becomes stabilized with the resources of its environment. A stable population is said to be in **equilibrium**, or at **saturation level**. This limit in population is a constant K and is imposed by the **carrying capacity** of the environment.

S-shaped curve is also called **Verhulst-Pearl logistic curve**. The sigmoid growth form is represented by the following equation

$$\frac{dN}{dt} = rN\left[\frac{K-N}{K}\right] = rN\left(1-\frac{N}{K}\right)$$

Where $\frac{dN}{dt}$ = rate of change in population size.

r = intrinsic rate of natural increase

N =population size

K= carrying capacity

$\frac{K-N}{K}$ = environmental resistance

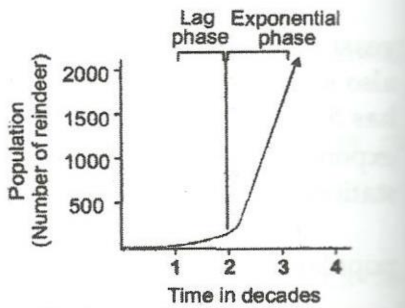
J-shaped growth curve

This type of curve was shown by a small population of reindeer experimentally reared in natural environment with plenty of food but no predators. There are only two phases in this curve, lag phase and exponential phase.

Lag phase: There was no significant increase in population of reindeer for some time in which the animals became adapted to their environment.

Exponential phase: On becoming adapted to their environment, the reindeer started reproducing rapidly. Rapid multiplication continued as long as enough food was available. Increase in population of reindeer resulted in corresponding decrease in the amount of food available to them. Finally, the food supply exhausted and this led to mass starvation and mortality.

Lemmings of tundra, some insects, algal blooms and annual plants also show J-shaped curves.



The J-shaped growth curve of reindeer

The J-shaped growth form is represented by the following exponential equation

$$\frac{dN}{dt} = rN$$

Where $\frac{dN}{dt}$ = rate of change in population size.

r = intrinsic rate of natural increase

N =population size

We can derive the integral form of the exponential growth equation as:

$N_t = N_0 e^{rt}$

Where N_t = population density after time t

N_0 = population density at time zero

r = intrinsic rate of natural increase

e = the base of natural logarithms (2.7 1828)

The population growth curve is S-shaped in most of the organisms. **Human population also shows S-shaped curve.**

According to *Mac Arthur* and *Wilson* (1967) populations are outcome of ***r*** or **k selection**. ***r*** selected population may exhibit more or less **'J'** shaped patterns and **k** selected population may exhibit more or less **'S'** shaped growth patterns.

3.5 POSITIVE AND NEGATIVE INTERACTIONS

5.10.4 Ecological interdependence and interactions

Under natural conditions organisms live together influencing each other life directly or indirectly. Members of biotic community are dependent on one another. The interdependence is reflected in their interactions, mainly for food, space, reproduction and protection. These interactions are important for the survival of different species and the community as a group. The interactions between populations of species in a community are broadly categorized into *positive* and *negative* interaction, depending on the nature of the effect on the interacting organisms.

Positive interaction

An interaction in which either both participating species or at least one of the participants gets benefits and neither is harmed is called *positive interaction* (also called facilitation).

Mutualism

Mutualism is a symbiotic relationship between members of two different species in which both members of the association benefit. This mutualism can be differentiated into obligate and facultative mutualism.

Obligate mutualism: In this relationship both organisms benefit by living in close association, and the relationship is obligatory. The term *symbiosis* is sometimes used in the same sense as mutualism. Symbiosis (termed used by de Barry in 1879) simply means *living together*. In narrowest sense, it is used to describe an association in which two species are deriving mutual benefit. However, now this term is used in a broad sense to describe all types of interactions. So, symbiosis is a close ecological relationship between the individuals of two (or more) different species.

Example of obligate mutualism

Nitrogen-fixing bacteria (*Rhizobium*) live in root nodules of legumes, where the bacteria, deriving nutrition from the host plant, fixes atmospheric nitrogen and make it available to the plants.

Lichens are plants made up of a fungus and an alga living in close association. They are usually found on rocks and tree trunks. The fungus is attached to the substratum by fungal threads. These fungal threads help absorb inorganic substances which are then used by the alga during photosynthesis (when organic compounds are made). The fungus obtains organic substances manufactured by the alga.

In the case of *coral reef*, coelenterates and algae live in obligate relationship.

Mycorrhizae are mutualistic relationship between fungi and roots of higher plants.

Facultative mutualism: Facultative mutualism is also called **protocooperation.** In this relationship both organisms benefit by living in close association, but is not obligatory. One good example is of a coelenterate, sea anemone – *Adamsia palliate* attached to the shells of hermit crab – *Eupagurus predeauxi*. The sea anemone is carried by the crab to fresh feeding sites and crab in turn is said to be protected from its enemies by sea anemone.

Commensalism

Commensalism means literally '*at table together*'. This is a symbiotic relationship between two species in which one species benefits and the other neither benefits nor suffers. Often, the host species provides a home and/or transportation for the other species.

Example

Epiphytes, e.g. some tropical orchids use trees or branches of trees for support without harm or benefit to the tree. Similarly several woody climbers take the support of the trees for exposing their canopy above ground without doing any harm to the tree itself. These relationships are also considered examples of commensalism.

The remora, a sucker-fish, lives in close association with sharks or other large fishes. The dorsal fin of the sucker-fish is modified to form a sucker; it uses this to attach itself to the shark. The sucker-fish is small and does not harm (or benefit) the shark.

Negative interaction

An interaction in which either both participating species or one of the participants gets harmed is called *negative interaction*.

Parasitism

Parasitism is a relationship between two organisms in which one species (parasite) benefits for growth and reproduction and other species (host) harmed. The host is the organism from which the parasite or parasitoid derives its sustenance. The hosts for parasite may be definitive host or intermediate host. The host in which parasites reaches maturity and if applicable reproduces sexually is called the *definitive host* (primary host) and other hosts are referred to as *intermediate hosts* (secondary host). The secondary host harbours the parasite only for a short transition period during which some developmental stages complete but do not perform sexual reproduction. For example, humans are a primary host for *Trypanosomes*, while a tsetse fly is the secondary host.

Parasitoid is different from parasite. Parasitoid is an organism that lives the entire life attached to or within a single host. Unlike a true parasite, however, it ultimately sterilizes or kills, and sometimes consumes, the host. Parasitoids are large relative to their hosts.

Parasites, like the predators, limit the population of the host species, but they are generally host-specific, and do not have choice or alternatives like predators. They are smaller in size and have higher biotic/reproductive potential compared to the predators. Parasites have poor means of dispersal and require specialized structures to reach or invade the host. Predators, on the other hand, are quite mobile and capable of capturing the prey.

Ectoparasites and endoparasites

Parasitic organisms can be differentiated into ectoparasites and endoparasites. Parasites that live inside the body of the host are called **endoparasites** (e.g. hookworms that live in the host's gut) and those that live on the surface of the hosts are called **ectoparasites** (e.g. some mites). Endoparasite can exist in one of two forms: intercellular or intracellular. A parasite that feeds on another parasite is termed *epiparasite* and relationship referred to as hyperparasitism.

Temporary parasites and permanent parasites

Temporary parasites are the parasites which come in contact with host for a brief period, e.g. female mosquitoes (*Anopheles*, *Culex*, *Aedes*), bedbug (*Cimes*), sandfly (*Phlebotomus*), tsetse fly (*Glossina*) whereas *permanent parasites* remain in contact with the host throughout their life, e.g. *Entamoeba histolytica, Ascaris lumbricoides, Taenia solium* etc.

Competition

Competition is an interaction among individuals striving for the same resource, resulting in reduced fitness in the competing individuals. In competition between two species both suffer adversely. Usually, competition occurs when resources, such as space, light and nutrients, etc. are in short supply. Competition can be *interspecific* or *intraspecific.*

Interspecific competition occurs between individuals of two different species occurring in a habitat. It is of two types: *interference* and *exploitation* competition. Interference competition is observed when two species come into direct contact with each other, such as fighting or defending a territory. The most obvious instances of interference competition are animals which fight over territories or food items. An example of interference competition is the phenomenon of allelopathy. *Allelopathy* involves negative interactions mediated by substances released by the competing populations. Black walnut trees are known for the production of *juglone*, an allelopathic compound that interferes with the growth of other plants. *Exploitation* competition is observed when one species exploits a resource such as food, space in common with another species without coming in its direct contact.

On the other hand, **intraspecific competition** occurs between individuals of the same species. Generally, the intraspecific competition is more intense than interspecific competition. Although there may be age differences or sex differences in resource utilizations, the requirement of individuals of the same species are very similar; hence, they compete more fiercely.

Table 5.6 Types of interactions between species

Interaction	*Species A*	*Species B*	*Result*
Neutralism	0	0	Neither affects the other.
Competition	–	–	A and B compete for the same resource, each has a negative effect on the other.
Parasitism	+	–	A, the parasite benefits.
Mutualism	+	+	A and B require each other to survive
Commensalism	+	0	A requires B to survive; B is not affected significantly.

Effect of competition

We can distinguish between long term and short term effect of competition. The short term effect, called *competitive exclusion*, occurs in ecological time scale. The long term effect, known as *character displacement*, operates on an evolutionary time scale.

Competitive exclusion principle

Competitive exclusion principle (also termed as *Gause's principle,* named after an eminent Russian ecologist) can be stated as: If two competing species coexist in a stable, homogeneous environment, then they do so as a result of niche differentiation, i.e. differentiation of their realized niches. If, however, there is no such differentiation, or if it is precluded by the habitat, then one competing species will eliminate or exclude the other. In the simplest form this principle states that a *complete competitor cannot coexist*.

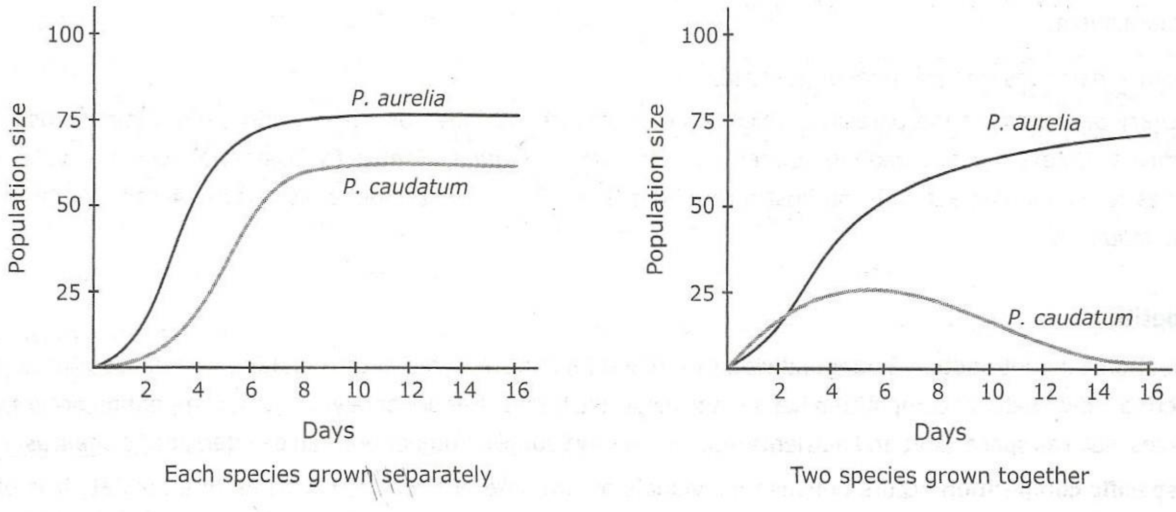


Figure 5.30 Growth of two species of paramecium in *separate cultures*, and in *mixed cultures*.