UNIT 3: ECOSYSTEM

Ecosystems are parts of nature where living organisms interact amongst themselves and with their physical environment. The term ecosystem was coined by Sir Arthur Tansley in 1935. Ecosystems vary greatly in size, such as a small pond or a large forest. Ecosystems can be recognized as self-regulating (own control of activities) and self-sustaining (able to persist by itself units of landscape. In nature two major categories of ecosystems may be distinguished: terrestrial and aquatic. Forests, grasslands, deserts are examples of terrestrial ecosystems. The aquatic ecosystems can be either fresh water (e.g. ponds, lakes, streams), or salt water (e.g. marine, estuaries) type.

Human activities may modify or convert natural ecosystems into anthropogenic or man-made ecosystems. For example, natural forests have been cut and the land converted to tree plantations or agricultural systems. Often dam construction involves submergence of forests and conversion to water reservoirs. Spacecrafts and aquariums may also be considered as man-made ecosystems. In this chapter, you will learn the basic concepts of ecosystem structure and function related to productivity, energy flow, decomposition and nutrient cycling. The general characteristics of major terrestrial ecosystems will also be described.

CONCEPT OF ECOSYSTEM

An ecosystem has two basic components: Abiotic (non-living) and Biotic (living organisms).

Abiotic components comprise inorganic materials (e.g. carbon, nitrogen, oxygen, CO_2 , water, etc.) and dead organic matter containing proteins, carbohydrates, lipids, humic substances, etc. Abiotic substances are present in soil, water and air. The climatic parameters like solar radiation and temperature determine the abiotic conditions within which the organisms carry out life functions.

Biotic components include producers, consumers and decomposers. **Producers** are the autotrophic (=self-nourishing), generally chlorophyll bearing organisms, which produce their own food (high energy organic compounds) by fixing light energy in the presence of simple inorganic abiotic substances. A variety of photosynthetic bacteria, chemosynthetic bacteria and photosynthetic protozoa also produce organic substances in terrestrial and aquatic habitats though in very small amounts. In terrestrial ecosystems the autotrophs are usually rooted plants (herbs, shrubs and trees), whereas in deep aquatic ecosystems floating plants called phytoplankton are the major autotrophs. In shallow waters rooted plants, **macrophytes**, are the dominant producers. When the environmental conditions are optimum, the phytoplankton may produce as much food as produced by the larger shrubs and trees on unit area (land or water surface) basis.

Consumers or phagotrophs (phago = to eat) are heterotrophic (=other feeding) organisms, mostly animals which generally ingest or swallow their food. The food of consumers consists of organic compounds produced by other living organisms. A consumer which derives nutrition by eating plants is called primary consumer or **herbivore** (e.g. grazing cattle). The secondary consumer or **carnivore** is an animal that devours the flesh of herbivore or other animals.

Decomposers or saprotrophs (sapro = to decompose) are other heterotrophic organisms, consisting mostly of bacteria and fungi which live on dead organic matter or detritus. Unlike consumers, the decomposers do not ingest (swallow) their food. Instead, they release different enzymes from their bodies which smear into the dead and decaying plant and animal remains. These enzymes bring about decomposition and breakdown of these remains. The extracellular digestion of the dead remains leads to the release of simpler inorganic substances into the soil which are then utilized by the decomposers.

Important aspects of concept of ecosystem are the phenomena of 'interrelationships' among the various components and the 'wholeness' of the interacting components. Various components of the ecosystem interact with and influence each other; for example, atmospheric temperature conditions or the availability of nutrients in soil affect the growth of plants. Similarly, the herbivores depend for food on producers, and interact with the latter while searching for food. The integration of numerous (in fact very large number of) interactions amongst components of ecosystem results in its characteristic wholeness.

Ecosystems can generally be physically delineated. But some times ecosystems intergrade with each other. At large spatial scale all ecosystems are interconnected by flow of energy and transfer of materials with the neighboring ecosystems, or even with distant ecosystems. For example, leaves of riverbank trees dropping in river water represent transfer of energy and material from terrestrial to aquatic ecosystem. Terrestrial birds diving to catch fishes in water bodies make similar transfers from aquatic to terrestrial ecosystems. Soil material may be eroded from a forest ecosystem and washed into the adjoining stream, or dust blown from a desert ecosystem may deposit over another ecosystem located miles away.

STRUCTURE AND FUNCTION OF ECOSYSTEM

Structure

Biotic and abiotic components are physically organized to provide a characteristic structure of the ecosystem. Important structural features are: **species composition** and **stratification.** Some ecosystems (e.g. tropical rain forests) show tall plant canopy and a bewildering number of biological species. On the other hand, the desert ecosystem shows a low, discontinuous herb layer consisting of fewer species and extensive bare patches of soil.

Another way to depict the ecosystem structure is through food relationships of producers and consumers. Trophic (food) structure of ecosystem is based on the existence of several trophic levels in the ecosystem. The producers form the first trophic level, herbivores the second and carnivores constitute the third. Trophic structure may be described in terms of amount of living material, called **standing crop**, present in different trophic levels at a given time. The standing crop is commonly expressed as the number or biomass of organisms per unit area. The biomass of a species is expressed in terms of either fresh or dry weight. Dry weight is preferred to avoid variations in weight due to seasonal moisture differences in biomass.

Nutrients necessary for the growth of living organisms are accumulated in the biomass and the abiotic components like soil. The amounts of nutrients such as nitrogen, phosphorus and calcium present in the soil at any given time is referred as the **standing state**. The standing states of nutrients differ from one ecosystem to another, or with seasons even in the same ecosystem.

Function

Ecosystems possess a natural tendency to persist. This is made possible by a variety of **functions** (activities undertaken to ensure persistence or continuance of life activities) performed by the structural components. For instance, green leaves of plants function as sites of food production, and plant roots absorb nutrients (chemical elements necessary for plant growth) from the soil. Herbivores perform the function of utilizing part of the plant production, and in turn serve as food for carnivores. Decomposers carry out the function of breaking down complex organic materials into simpler inorganic products which can be used by the producers. These functions are carried out in the ecosystem through delicately balanced and controlled **processes**. For example, the process of photosynthesis is involved in food production, and that of decomposition leads to release of nutrients contained in the organic matter.

A knowledge of the rates at which different processes occur in ecosystem is necessary to understand the interrelations of ecosystem structure and function. The key functional aspects of the ecosystem are: (1) Productivity and energy flow; (2) Nutrient cycling; (3) Development and stabilization.

MAJOR FUNCTIONAL PROCESSES IN ECOSYSTEM

Productivity

The rate of biomass production is called productivity. Productivity in ecosystems is of two kinds, primary and secondary. **Primary productivity** refers to the rate at which sunlight is captured by producers for the synthesis of energy-rich organic compounds through photosynthesis. Productivity is a rate function and is expressed in terms of dry matter produced or energy captured per unit area of land per unit time. It is generally expressed in terms of g m^{-2} $year^{-1}$ or kcal m^{-2} $year^{-1}$. Hence, the productivity of different ecosystems can be easily compared. Primary productivity has two aspects, gross and net. The rate of total capture of energy or the rate of total production of organic material (biomass) is known as **gross primary productivity**. However, while the energy capture process is operating in the green tissues, these as well as other tissues are consuming energy in respiration. The balance energy or biomass remaining after meeting the cost of respiration of producers is called **net primary productivity** as shown below.

Net productivity = Gross productivity – respiration rate

The net primary productivity results in the accumulation of plant biomass which serves as the food of herbivores and decomposers. At the trophic level of consumers, the rate at which food energy is assimilated is called **secondary productivity**. It should be recognised that the food of consumers has been produced by the primary producers, and secondary productivity reflects only the utilization of this food for the production of consumer biomass.

The magnitude of primary productivity depends on the photosynthetic capacity of producers and the prevailing environmental conditions, particularly solar radiation, temperature and soil moisture. In tropical regions primary productivity may be sustained throughout the year provided adequate soil moisture remains available. However, in temperate regions primary productivity is severely limited by cold climate and short a snow-free growing period during the year. Table 3.1 shows plant biomass and net primary productivity of major ecosystems of the world. High level of net primary productivity (= 20 t ha^{-1} $year^{-1}$) has been recorded for mature tropical rain forests. Deserts generally fall in the lowest productivity category (<1 t ha^{-1} $year^{-1}$).

Table 3.1. Geographical Area, Mean Plant Biomass and Net Productivity in Major World Ecosystems.

Ecosystems	Area (10^6 km^2)	Mean plant biomass (t ha^{-1})	Mean net primary productivity (t ha^{-1} $year^{-1}$)
Tropical rain forest	17	440	20
Tropical deciduous forest	8	360	15
Temperate deciduous forest	7	300	12
Temperate coniferous forest	12	200	8
Savanna	15	40	12
Temperate grassland	9	20	5
Desert shrub	18	10	0.7

t = ton = 1000 kg
ha = 1000 m^2

In aquatic ecosystems productivity is generally limited by light, which decreases exponentially with increasing water depth. In deep oceans, nutrients often become limiting for productivity. Nitrogen is regarded as the most important nutrient limiting productivity in marine ecosystems.

Decomposition

While productivity involves synthesis and building processes, equally important is decomposition which concerns breakdown of complex organic matter by decomposers to inorganic raw materials like carbon dioxide, water and various nutrients. The upper layer of soil is the main site for decomposition processes in the ecosystem.

Dead plant parts and animal remains are called **detritus**. Dried plant parts like leaves, bark, flowers, etc. and dead remains of animals including faecal matter drop over the soil and constitute the **aboveground detritus** (also known as **litter fall**). The **belowground detritus** is primarily composed of dead roots (also called **root detritus**). With the passage of time, decomposing detritus loses weight until it disappears completely. If decomposition is retarded or stopped, large amounts of partially decomposed organic matter shall accumulate in the ecosystem.

Decomposition processes: As shown in Figure 3.1 decomposition involves several processes. These processes can be categorized as fragmentation of detritus, leaching and catabolism.

(i) The **fragmentation of detritus,** mainly due to the action of detritus feeding invertebrates (**detritivores**), causes it to break into smaller particles. The detritus gets pulverized when passing through the digestive tracts of animals. Due to fragmentation the surface area of detritus particles is greatly increased.

(ii) Water percolating through soil removes soluble substances (eg. sugars, several nutrients) from the fragmented detritus due to **leaching** action.

(iii) The extracellular enzymes released by bacteria and fungi carry out **catabolism** i.e. enzymatic conversion of the decomposing detritus to simpler compounds and inorganic substances. It is important to know that all the three decomposition processes operate simultaneously on the detritus.

Humification and **mineralization** occur during decomposition in the soil (Fig. 3.1). Humification leads to accumulation of a dark coloured amorphous substance called **humus**. Humus is highly resistant to microbial action and undergoes extremely slow decomposition. It serves as a reservoir of nutrients. Mineralization results in the release of inorganic substances (e.g. CO_2, H_2O) and available nutrients (NH_4^+, Ca^{++}, Mg^{++}, K^+ etc.) in the soil.

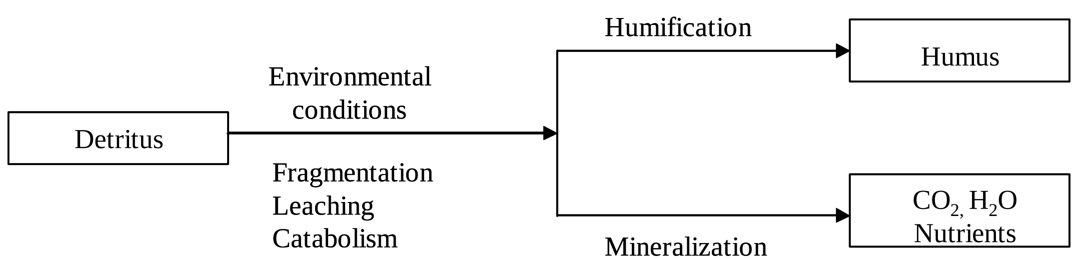

Fig. 3.1. Processes involved in decomposition of detritus; the end result of decomposition is formation of humus and release of CO_2, H_2O and nutrients.

Under certain conditions, soil nutrients get tied up with the biomass of microbes and become temporarily unavailable to other organisms. Such incorporation of nutrients in living microbes is called **nutrient immobilization**. Nutrients remain immobilized for variable periods and get mineralized later after the death of microbes. This immobilization prevents the nutrients from being washed out from the ecosystem.

Factors affecting decomposition: The rate of decomposition of detritus is primarily regulated by the climatic factors and the chemical quality of detritus. Amongst climatic factors, the key role is played by temperature and soil moisture through their regulatory effect on the activities of soil microbes.

Detritus decomposes very rapidly, within a few weeks or months, in a climate characterized by higher temperature (>25 °C) and moist conditions (e.g. in humid tropical regions). Low temperature (<10 °C) sharply reduces decomposition rate even if moisture is in plenty. For example, in regions of high latitude or altitude complete decomposition of detritus may require several years or decades. Decomposition rate is also low under prolonged soil dryness even if the temperature remains high (e.g. in tropical deserts).

The accumulation of certain substances in the detritus either promotes or retards decomposition rate. The chemical quality of detritus is determined by the relative proportions of water soluble substances (including sugars), polyphenols, lignin and nitrogen. Within the same climatic conditions decomposition rate is slower if the detritus is rich in substances like lignin and chitin. The nitrogen-rich detritus having low amounts of lignin decomposes relatively rapidly. The actual rate of decomposition of detritus in natural conditions depends upon the integrated effect of environmental conditions and detritus quality.

ENERGY FLOW IN THE ECOSYSTEM

Energy flow is the key function in the ecosystem. The storage and expenditure of energy in the ecosystem is based on two basic laws of thermodynamics. In accordance with the **first law of thermodynamics (**which states that energy is neither created nor destroyed, but can be transferred from one component to another, or transformed from one state to another), energy of sunlight can be transformed into energy of food and heat. No energy transformation occurs spontaneously unless energy is degraded or dissipated from a concentrated to a dispersed form (**second law of thermodynamics)**. Thus, in ecosystem, the transfer of food energy from one organism to another leads to degradation and loss of a major fraction of food energy as heat due to metabolic activities, with only a small fraction being stored in living tissues or biomass. While energy in food is in concentrated form, heat energy is highly dispersed. It must be understood that all changes in energy forms can be accounted for in any system.

It is useful to examine the relationship between incident radiant energy and the energy captured by the producers in the food they manufacture (Fig. 3.2). Only the visible light or the **photosynthetically active radiation (PAR)** which carries about 50% of the energy of total incident solar radiation is available to producers for absorption. By multiplying the estimated productivity with the **calorific value** (i.e. energy content per unit weight) of biomass the energy captured can be determined. The calorific value is determined by burning known weight of dry biomass in a bomb calorimeter in the presence of oxygen, and measuring the heat evolved.

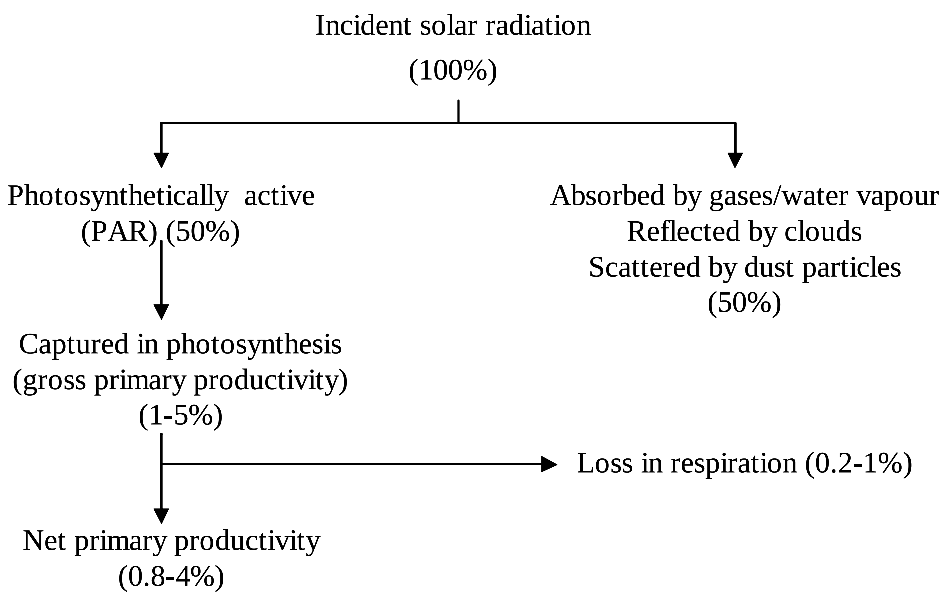

Fig.3.2. Fate of solar radiation incident on plant canopy; values in parentheses represent fraction of incident solar radiation.

Under favourable environmental conditions only about 1-5% energy of incident radiation or 2-10% of PAR 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% of the incident total radiation or 1.6-8% of PAR. Only the energy captured in net productivity of producers can be used by other trophic levels.

Food chain and food web

All trophic levels in an ecosystem are connected by transfer of food or energy. The transfer of energy from one trophic level (e.g. producers) to the next trophic level (e.g. consumers) is called **food chain**. Two types of food chains can be distinguished in all ecosystems, **grazing food chain** and **detritus food chain**. Grazing food chain extends from producers through herbivores to carnivores. Cattle grazing in grasslands, deer browsing in forest and insects feeding on crops and trees are most common biotic constituents of the grazing food chain. Detritus food chain begins with dead organic matter and passes through detritus-feeding organisms in soil to organisms feeding on detritus-feeders. A much larger fraction of energy flows through the detritus food chain. Different food chains are often interconnected, e.g. a specific herbivore of one food chain may serve as food of carnivores of several other food chains. Such interconnected matrix of food chains is called **food web**.

Energy flow model

A simplified representation of energy flow through ecosystem has been made in Figure 3.3. Two aspects with respect to energy flow in ecosystem need careful consideration. First, the energy flows *one way*, i.e. from producers through herbivores to carnivores; it can not be transferred in the reverse direction. Second, the amount of energy flow decreases with successive trophic levels. Producers capture only a small fraction of solar energy (1-5% of total solar radiation) and the bulk of unutilized energy is dissipated mostly as heat. Part of the energy captured in gross production of producers is used for maintenance of their standing crop (respiration) and for providing food to herbivores (**herbivory**). The unutilized net primary production is ultimately converted to detritus, which serves as energy source to decomposers. Thus, energy actually used by the herbivore trophic level is only a small fraction of the energy captured at the producer level. On an average, in different ecosystems the herbivore assimilation or productivity approximates 10% of gross productivity of producers.

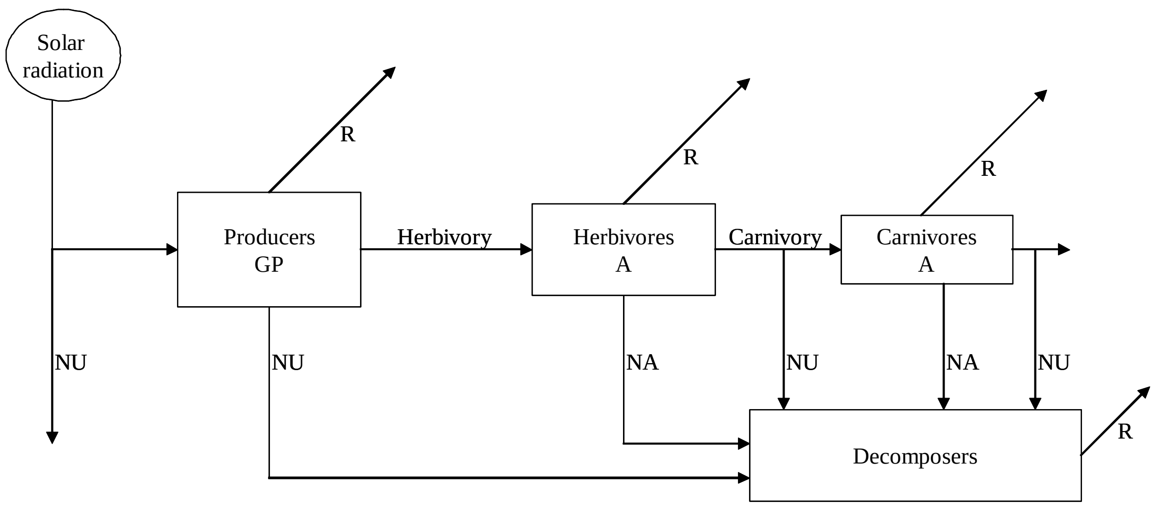

Fig. 3.3. A generalized energy flow model of ecosystem; boxes represent biotic components and the arrows show the pathways of energy transfer; code: SR, Solar radiation; GP, Gross primary productivity; A, Assimilation; R, Respiration; NU, Not utilized; NA, Not assimilated.

The energy assimilated by the herbivores is used in respiration and a fraction of unassimilated energy is transferred to decomposers (e.g. fecal matter). The remaining herbivore level energy is either utilized by the carnivores, or gets transferred to decomposers after the death of herbivores. Again, only a small fraction (about 10%) of herbivore productivity is used to support carnivore productivity. Similarly, the energy available at carnivore trophic level is again partitioned, leaving a very small fraction to support the next trophic level (top carnivore).

The respiration cost also increases sharply along successive higher trophic levels. On an average, respiration of producer consumes about 20% of its gross productivity. Herbivores consume about 30% of assimilated energy in respiration. The proportion of assimilated energy consumed in respiration rises to about 60% in carnivores. Because of this tremendous loss of energy at successive higher trophic levels, the residual energy is decreased to such an extent that no further trophic level can be supported. Therefore, the length of food chains in an ecosystem is generally limited to 3-4 trophic levels.

ECOLOGICAL PYRAMIDS

Trophic structure in ecosystem can be represented by comparing standing crop (either number of individuals or biomass) or energy fixed per unit area at different trophic levels. Graphical representation of the trophic structure is done by drawing ecological pyramids, where the basal, mid and top tiers show the parameter values for producers, herbivores and carnivores in the ecosystem (Fig. 3.4). Common parameters used for constructing ecological pyramids are number of individuals (**pyramid of numbers**), dry weight (**pyramid of biomass**) or rate of energy flow (**pyramid of energy**) at successive trophic levels.

In most ecosystems the pyramids of number and biomass are upright i.e. producers outnumber and outweigh the herbivores, and herbivores outnumber or outweigh the carnivores. However, in certain ecosystems the pyramid of number (e.g. in tree dominated ecosystems) and the pyramid of biomass (e.g. in deep water bodies) may look inverted. For example, numerous small insects may occur on a single tree, and in oceans the combined weight of numerous small short-lived phytoplankton organisms at a given time is exceeded by the combined weight of large, long-lived fishes. The pyramid of energy, however, is always upright. Amongst the three kinds of ecological pyramids, the pyramid of energy, which expresses mainly the rate of food production, can be considered most representative of the functional characteristics. It emphasizes that total energy flow at successive trophic level always decreases compared to the preceding trophic level (explanation: lesser energy flow at herbivore trophic level compared to producer trophic level, and so on).

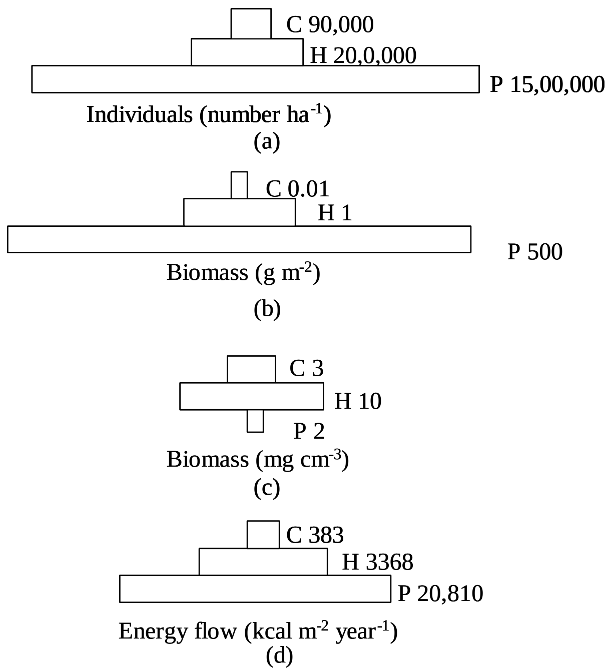

Fig. 3.4. Ecological Pyramids; code: (a) Pyramid of number in a grassland, (b) Pyramid of biomass in a fallow land, (c) Inverted pyramid of biomass in a lake, (d) Energy pyramid in a spring ; P - Producer, H - Herbivore, C – Carnivore.

NUTRIENT CYCLING

The living organisms require several chemical elements for their life processes. Plants can photosynthesize simple compounds like carbohydrates using carbon, hydrogen and oxygen obtained from carbon dioxide and water; however, for the synthesis of more complex materials (e.g. proteins) they requires supply of additional essential elements or nutrients. Some nutrients are required in large amounts (e.g. nitrogen and phosphorus) but several others are needed in trace amounts (e.g. zinc, molybdenum, copper etc.). Nutrients may be used as part of the structural components or as components of enzymes which mediate various life processes.

Unlike energy which flows unidirectionally, nutrients are continually exchanged between organisms and their physical environment. **Nutrient cycles** involve storage and transfer of nutrients through various components of the ecosystem so that the nutrients are repeatedly used. Another term **biogeochemical cycle** (bio = living organisms and geo = rocks, air and water) also denotes nutrient cycling. But biogeochemical cycle is generally considered in a regional or global context.

Bulk of nutrients are stored in abiotic reservoirs in relatively inactive state and a smaller active fraction, often existing in ionic form is involved in cycling. Nutrient cycles are of two types, the **gaseous** and the **sedimentary**. The reservoir of gaseous type of nutrient cycle is generally located in the atmosphere or the hydrosphere. But in the sedimentary type the reservoir exists in the earth`s crust. Nitrogen (reservoir in atmosphere) and phosphorus (reservoir in lithosphere) cycles are well known examples of gaseous and sedimentary types, respectively.

Nutrient cycles can be conveniently considered under the following three aspects as shown in Fig. 3.5.

Input of Nutrients: Ecosystem receives nutrients from external sources and stores them for further use through biological processes. For example, nutrients in dissolved state are gained from rainfall (**wet deposition**) or in particulate state from dust fall (**dry deposition**). Symbiotic biological fixation of nitrogen in soil also represents an input. Weathering of soil parent materials which releases available nutrients from their fixed state is another example of input.

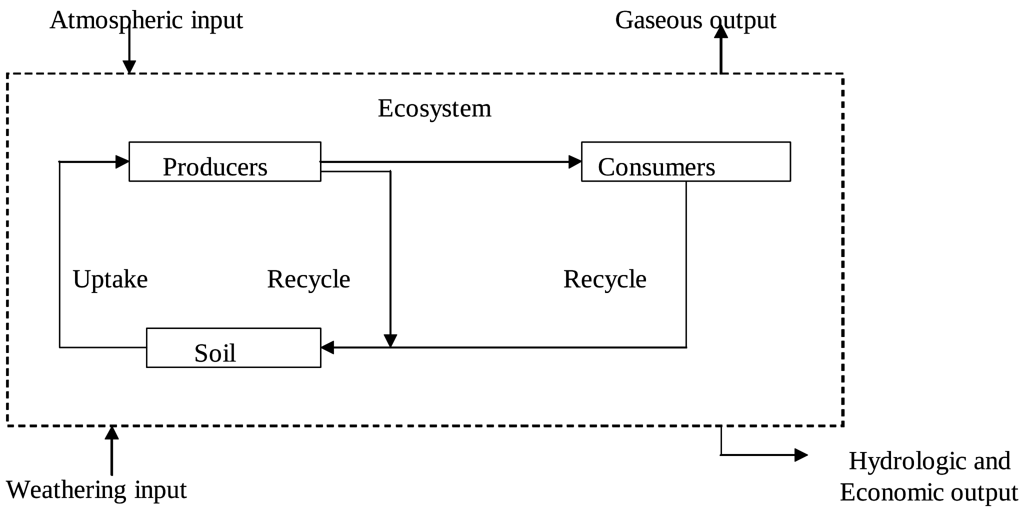

Fig. 3.5. A generalized model of ecosystem nutrient cycling; nutrients are brought in (input), moved out (out put), and cycled internally in the ecosystem; boxes represent ecosystem components and arrows show the pathways of nutrient transfers.

Output of Nutrients: Nutrients are moved out of an ecosystem and many become input to another ecosystem. For example, considerable loss of nutrients like calcium and magnesium occurs through runoff water or through soil erosion. Significant amount of nitrogen may be lost in gaseous form by the denitrification process in soil. Harvesting of agricultural crops or transportation of logs from forests represent nutrient loss from these ecosystems.

In an undisturbed ecosystem (i.e. an ecosystem in which human activities are absent or nearly so) the input of nutrients may approximately equal the output of nutrients, rendering the nutrient cycles more or less balanced. Generally the absolute amounts of nutrient moving in (input) and moving out (output) of the ecosystem are much less than the amount of nutrients cycled within (amongst different components) the ecosystem. Severe disturbances in the ecosystem (e.g. tree felling, insect out break, fire, soil erosion, etc.) may make the nutrient cycles unbalanced and the ecosystem unstable. To exemplify, after removal of natural vegetation the soil can be lost rapidly by erosion.

Internal Nutrient Cycling: Plants absorb varying amounts of nutrients from the soil. Due to decomposition of dead organic matter nutrients are continuously regenerated and stored in soil in forms available to the plant. A dynamic state exists in soil with nutrient regeneration and absorption occurring simultaneously. The transfer of nutrients from the soil to plants by the process of nutrient absorption is known as **uptake**. The absorbed nutrients are metabolically incorporated in plants during growth. Periodically nutrients are recycled, i.e. brought back to soil through **litter fall** from vegetation, animal remains and faecal matter, etc.. The aboveground as well as root detritus decompose to regenerate the nutrients. Eventually nutrients contained in the detritus on soil surface and within, are regenerated by decomposition in plant-available forms.

When the uptake of nutrients exceeds the amount recycled (e.g. as in the case of a young growing forest), a fraction of the uptake is retained in the standing crop. This **retention** of balance nutrients in the standing crop leads to increase in nutrient content of the ecosystem. Thus, in a nutrient cycle:

$$\text{Retention} = \text{Uptake} - \text{Recycle}$$

Rates of nutrient uptake, recycle and retention vary widely in different ecosystems. A large number of chemical methods are available for determining the amounts of different nutrients per unit weight of biomass or soil. By determining changes in the nutrient concentrations and biomass with time the nutrient budget of the ecosystems can be computed.

ECOLOGICAL SUCCESSION

The biotic communities are dynamic in nature and change with passage of time. The successive replacement of communities in an area over a period of time is known as **ecological succession.** Both abiotic and biotic components show changes during succession. Succession is a community–controlled phenamena, which results due to the action and co-action on living organisms. Physical environment often determines the nature, direction, rate and optimal limit of change.

During succession, changes occur both in plant and animal communities. The changes in plant community are, however, more marked and visible. It is possible to distinguish two basic kinds of succession. When the succession takes place on new sites (previously unoccupied by organisms), it is called **primary succession**. Examples of primary succession sites are: bare rocks, glacial moraines (formed after glaciers have moved away), volcanic lava deposits etc. Such sites, which are invaded by organisms for the first time, are limited in area. Much larger surface of earth is covered with plants, but the existing plant cover is often partially or completely destroyed due to some disturbance caused by events like fire, landslide, forest felling etc. In such situations after the cessation of disturbance the plant cover gradually develops again through the process called **secondary succession**. Forests destroyed by fire or felling may show reoccupation of the site by herbs followed by woody species. In the practice of shifting cultivation when the tribals abandon cultivation (begun after forest felling) and move to new sites, the abandoned fields gradually get converted into a forest by secondary succession. Expectedly secondary succession occurs over much larger area than primary succession.

Whenever succession begins on bare land or in a previously occupied habitat, the plant species colonizing in the beginning are called **pioneer species**. Commonly the pioneer plant species are small in size (e.g. herbs), short-lived (e.g. annuals), and rapidly growing. Pioneer species have to grow in relatively harsh habitat conditions where adequate supply of water and nutrients may not be assured. Hence, such species have evolved life history strategy to complete growth and reproduction within short time when optimum environmental conditions are available in the habitat. The initial community developing through the assemblage of the pioneer species is called **pioneer community**. With the passage of time, the pioneer community shows change in species composition due to disappearance of pioneer species and colonization of new species. Thus, the pioneer community is replaced by second community, then second community is replaced by the third, and the process goes on. The successive communities at a site are called **seral communities**, with each community representing a **seral stage**. The species coming in early during succession are known as **early successional species,** and those making appearance much later are called **late successional species.**

By the time the late successional species get established the community becomes complex, being comprised of a large number of species showing intricate mutual interactions. Successive appearance of mosses, herbs, shrubs and trees at a site generally correspond to replacement of a community by next community, and this way ultimately the terminal community of succession called **climax community** is reached. The sequence of communities succeeding each other during the course of succession represents the **sere.** Compared to preceding communities, the climax community is stable. The species composition of the climax community remains unchanged as long as the environmental conditions remain unaltered and no disturbance sets in. The time required to attain climax stage varies widely with the nature of community; for instance, grassland community may reach climax stage within few years or decades, but forest succession may require several decades, sometimes more than a century, to attain climax stage.

When succession proceeds in aquatic conditions (e.g. pond, lake), it is known as **hydrarch succession**, and succession occurring on land deficient in moisture is called **xerarch succession**. In xerarch succession, generally lower plants like lichens and mosses are pioneer species, which are followed by invasion of herbaceous plants, and finally the climax community is established. The climax in xerarch succession may be represented by a grassland community in lower rainfall conditions. In higher rainfall conditions the xerarch succession may lead to the formation of a forest community. The hydrarch succession in standing water begins with the pioneer community formed by phytoplankton and zooplankton. As a result of silting in the water body due to soil erosion from surrounding areas, the pond bottom is raised causing replacement of the pioneer community by rooted plants with leaves floating or emerged over water surface. With the continuance of silting and accumulation of decomposing plant residues the water body gradually gets filled up, making way for the establishment of terrestrial plants like grasses. Thus, hydrarch succession may lead to the disappearance of the water body which is converted into terrestrial conditions.

MAJOR ECOSYSTEMS

The regional biotic units, the biomes, are easily recognized by the life form of the climax vegetation. But the biome includes besides the climax community all associated developing and modified communities occurring within the same climatic region. Thus, biome in a large regional entity, often encompassing several ecosystems showing certain common features. For instance, a forest biome may include young successional forests and open grass-dominated tracts located within the large expanse of mature forest. Ecological characteristics of typical forest, grassland/savanna, and desert ecosyetems are described below.

Forest ecosystem

The characteristic vegetation of forest ecosystem is dominated by densely growing trees having a closed, or nearly so, canopy cover. Depending upon the climate type, a wide variety of forest types occur in the world. Forests found in colder temperate regions differ from the forests in tropical regions in terms of structure, productivity and nutrient cycling. In the northern hemisphere, as one proceeds from the equator north-ward to arctic region consecutive belts of tropical, temperate deciduous and temperate coniferous forests are observed. Tropical rain forests occur in warm and high rainfall regions (near equator) of the world with plenty of soil water availability throughout the year. On the other hand, tropical deciduous forests extend to the outer tropics having lesser seasonal rainfall and prolonged soil drought during the year. The temperate forests are distributed in mid-latitudes (40-60° N lat.), include two contrasting types, dominated by either broadleaf deciduous species, or by needle-leaf evergreen species. Temperate broadleaf forests experience relatively mild cool environment but the climate in temperate needle-leaf coniferous forests are cold with the ground being covered with snow for 5-6 months.

Major forest ecosystems in India are:

(i) Tropical rain forest ecosystem

(ii) Tropical deciduous forest ecosystem

(iii) Temperate broadleaf forest ecosystem

(iv) Temperate needle-leaf or coniferous forest ecosystem.

In India the temperate forests occur at >1500 m altitude in the Himalaya. The climatic features of four major forest biomes of India are given in Table 3.2.

Table 3. 2. Typical Climatic Conditions in Major Forest Types in India.

Forest type	Mean annual temperature (°C)	Mean annual rainfall (mm)	Dry months during the year*
Tropical rain forest	23-27	2000-3500	2-3
Tropical deciduous forest	22-32	900-1600	6-8
Temperate breadleaf forest	6-20	1000-2500	3-5
Temperate needleleaf forest	6-15	500-1700	3-5

* Month in which rainfall is <50 mm.

Tropical rain forests: In India, tropical rain forests are discontinuously distributed mainly along Western Ghats and in North-eastern Himalaya. Dipterocarpus and Hopea are the most common tree species in Indian rain forests. These evergreen tropical rain forests, possessing highest standing crop biomass among all biomes, show 30-40 m tall canopy structure with 4-5 strata formed by different plant species. Some of the dominant trees have umbrella like canopy extending above the general canopy of the forest. Many tree species show buttresses (swollen stem bases), large leaves with drip tips and round the year leaf fall. Woody climbers and epiphytes grow profusely in these forests. The soil of rain forest is highly leached and has low base content. Large amounts of nutrients in rain forests are stored in the tall vegetation, whereas the nutrient storage in soil is low.

Tropical deciduous forests: The tropical deciduous forests occur widely in the northern and southern parts of our country in plain and low hilly areas. Towards the north-west, the deciduous forests grade into thorn forests. Sal (*Shorea robusta*) and teak (*Tectona grandis*) are the dominant tree species in deciduous forests. Other useful species are tendu (*Diospyros melanoxylon*), chiraunji (*Buchanania lanzan*), khair (*Acacia catechu*). These forests are of short stature (10-20 m height) and show contrasting seasonal aspects. During rainy season the forest is lush green with dense foliage and thick herbaceous layer. But the leaves of most tree species drop before the advent of summer, turning the forest largely leafless along with dried up herbaceous layer. Many tree species possess thick barks giving protection from frequent fires. The deciduous forest soil is richer in nutrients due to lesser leaching.

Temperate broadleaf forests: Temperate broadleaf forests mainly occur between 1500 and 2400 m altitude in the western Himalaya. Several species of oak (*Quercus*) predominate in the temperate broadleaf forests These includes banj oak (*Quercus leucotrichophora*), khrsn oak (*Q. semecarpifolia*), tilonj oak (*Q. floribunda*) and rianj oak (*Q. lanuginose*). All oak species in the Himalayan region are evergreen. The evergreen oaks in Himalaya show peak leaf fall during summer but never become leaf less. These four strata forests, extend to 25-30 m height. The tree canopy is dense, herbaceous layer is least developed, and grasses are generally lacking. The oak forests are often rich in epiphytic flora.

Temperate needle-leaf or coniferous forests: In the Himalaya the temperate needle-leaf coniferous forests are distributed over 1700 to 3000 m altitude. The temperate needle-leaf or coniferous forests contain economically valuable gymnospermous trees like the pine (*Pinus wallichiana*), deodar (*Cedrus deodara*), cypress (*Cupressus torulosa*), spruce (*Picea smithiana*) and silver fir (*Abies pindrow*). Coniferous forests are taller (30-35 m) and possess evergreen canopy of long needle-like leaves. In different species needle leaves may persist on the canopy for 2-7 years, therefore the canopy always remains green. In many species the canopy is cone shaped.

Grassland and savanna ecosystems

Grassland ecosystem: Grassland ecosystems have treeless herbaceous plant cover dominated by a wide variety of grass species (family, Poaceae). Associated with grasses are several herbaceous dicotyledonous species, especially legumes which play important role in nitrogen economy. Amongst the best known grassland biomes are the extensive “prairie” in the north America and “Steppe” in Russia. The rainfall in grassland region is considered too low to support a forest and much higher than the rainfall in deserts.

Grazing by large herbivores and fire play significant role in maintaining the dominance of grasses and eliminating the invasion of woody species. Morphologically, grasses are either sod-formers, which develop a solid mat of grass cover, or bunch grasses which grow in separate bunches. The height of grassland vegetation is highly variable ranging from as low as few centrimeters in arid regions to more than one and half meters in moist regions. Corresponding to above height range the shoot biomass may vary widely from about 50 to 1000 g m^{-2}. Most remarkable aspect of grassland structure is its extensive root system, highly ramifying through the soil horizons. The primary productivity in grassland is directly related to the amount of rainfall.

Savanna ecosystem: Commonly the term savanna implies a well developed grass cover interspersed with scattered shrubs or small trees. The height of woody species may vary from 1-8 meters. Savannas are widely distributed in warm parts of central and southern Africa, India, northern and east-central south Africa and northern Australia. Although some savannas may be natural, many others are anthropogenic. In India all savannas are believed to be derived by the degradation of original tropical forests and maintained in their current state by continued grazing and fire for centuries.

Most abundant grasses in Indian savannas are *Dichanthium, Sehima, Phragmites, Saccharum, Cenchrus, Imperata* and *Lasiurus*. Generally, the woody species in a savanna are the residual species from the original forest from which the savanna has been derived. Some common trees and shrubs in savannas are *Prosopis, Zizyphus, Capparis, Acacia, Butea* etc.

Savannas occur in tropical areas with highly seasonal climate having distinct wet and dry periods. Availability of soil moisture determines the species composition and productivity of savannas. The effect of soil moisture variation may be modified by fire, soil nutrients and herbivores. An important aspect of tropical savannas is the abundance of grass species possessing C_4 photosynthetic capability. As you know, these species are able to sustain high level of primary productivity even with low soil moisture availability. Although the root system of grasses is well developed in the upper 30 cm soil horizons, the woody species usually send their roots to deeper horizons.

Desert ecosystem

Desert biome experiences prolonged moisture scarcity. Deserts have been variously classified as true deserts, having less than 120 mm annual rainfall or **extreme desert** showing less than 70 mm yr^{-1} rainfall. On the basis of temperature, deserts are distinguished into **hot deserts** and **cold deserts**. Nevertheless, in desert biomes evaporation from soil always exceeds rainfall by 7 to 50 times. Most of the deserts are distributed around the Tropic of Cancer and Tropic of Capricorn between 15° and 35° latitudes in both northern and southern hemispheres. Warm or hot day and cool night are the characteristics of most deserts. The biomass and primary productivity levels in deserts are low.

The desert vegetation is dominated by three life forms: (1) ephemeral annual herbs which grow only when there sufficient moisture is available, (2) typical succulent xerophytes like cacti which store water, and (3) shrubs and small trees like *Prosopis, Salvadora* and *Tamarix*, whose deep tap roots may reach the water table. In some deserts tall succulents, mostly cacti, become highly noticeable projecting above the general canopy. *Cenchrus* is an abundant grass in the desert regions.

Aquatic ecosystems

Aquatic habitats have water as the principal external as well as internal medium. Fresh water habitats may be conventionally recognized in two categories:

1. Standing-water or lentic habitats; e.g. lakes, pond, swamp or bog.
2. Running-water or lotic habitats; e.g. spring, stream or river.

Often there is no sharp boundary between categories or within water bodies of same category. Fresh water habitats occupy a relatively small portion of earth's surface as compared to terrestrial and marine habitats, but their importance is far greater than their area for the following reasons:

1. They are the most convenient and cheapest source of water for domestic and terrestrial needs;
2. Fresh water bodies are critical components of hydrological cycle;
3. They provide convenient and cheapest waste disposal systems.

However, the abuse of this natural resource is leading to water grave crisis, which will become a limiting factor for man if proper water conservation methods are not used urgently.

Lakes and ponds: The life span of ponds ranges from a few weeks or months in case of small ponds to several hundred years for larger ponds. Some lakes are ancient, eg. Chilka lake. Standing water bodies are expected to change with time at rates more or less inversely proportional to its size. Distinct zonation and stratification are characteristics features of lakes and large ponds. Typically, one may distinguish a **littoral zone** containing rooted vegetation along stream, a **limnetic zone** of open water dominated by plankton, and a deep-water **profundal zone** containing only heterotrophs. In temperate regions lakes after become thermally stratified during summer and again in winter, owing to differential heating and cooling. The upper part of the lake, or **epilimnion**, becomes temporarily isolated from the lower water, or **hypolimnion**, by a **thermocline** zone that acts as a barrier to exchange of materials. Consequently, the supply of oxygen in the hypolimnion and nutrients in the epilimnion may run short. During spring, as the entire body of water approaches the same temperature, mixing occurs again. "Blooms" of phytoplankton often follow this seasonal rejuvenation of the water body.
Constructing artificial ponds and lakes (impoundments) is one of the conspicuous ways in which man changes the landscape in regions that lack natural bodies of water. Since shallow water bodies can be as productive as an equal area of land, **aquaculture** can be a useful supplement to agriculture, especially where land is scare. However, one should not think that once a water body has been created, it will always remain as such.

Instead, all the biological process of succession will take place, apart from soil erosion in the poorly protected watershed all around, causing disappearance of the pond/lake in the long run. Thus, appropriate conservation of such water bodies is required including periodical draining of its water.

Rivers and estuaries: Rivers have greatly affected human history in terms of location of settlements. The flow of water in rivers varies seasonally, and oxygen and suspended matter are two factors that often become critical. For instance, during the rainy season many rivers carrying heavy silt load become muddy with much reduced transparency in water. Two categories of the flowing water ecosystem, rivers, have been distinguished: (1) streams in which basin is eroding and the bottom, therefore, is generally firm, and (2) stream in which material is being deposited and, therefore, the bottom is generally composed of soft sediments. In many cases these situations alternate in the same stream, as may be seen in “rapids” and “pools” of small streams. Aquatic communities are quite different in the two situations owing to the rather different conditions of existence. The communities of pools resemble those of ponds in that a considerable development of phytoplankton may occur and the species of fish and aquatic insects are the same or similar to those found in ponds and lakes. The life of hard-bottom rapids, however, is composed of more unique and specialized forms.

When rivers meet the sea (having saline water), at the junction develop the **estuaries,** where salinity level keeps fluctuating with tide. At high tide the inflowing sea water makes the estuary highly saline, while at low tide with water draining into the sea and river water flowing in, the salinity level drops. The organisms have evolved many adaptations to cope with tidal cycles and salinity changes. Tidal action promotes a rapid circulation of nutrients and food, and aids in the rapid removal of waste products of metabolism. The estuaries are one of the most productive regions of the world.