3 Ecosystem

INTRODUCTION

A biotic community lives in an environment, which provides material, energy requirement and other living conditions to it. The biotic community together with the physical environment forms an interacting system called **ecosystem**. The term ecosystem was introduced by **Sir Arthur Tansely** (1935). An ecosystem can be defined '*as a structural and functional unit of biosphere or segment of nature consisting of community of living beings and the physical environment both interacting and exchanging materials between them*'. In an ecosystem the biotic communities and abiotic environment influence each other. This relationship is called **holocoenosis**.

TYPES OF ECOSYSTEM

An ecosystem may be natural (*e.g.*, lake, forest, grassland etc.) or man-made (*e.g.*, an aquaria, crop field etc.), temporary (*e.g.*, rainfed pond) or permanent (*e.g.*, lake, forest etc.), aquatic (*e.g.* pond, ocean etc.) or terrestrial (*e.g.*, grassland, forest etc.). The aquatic ecosystems can be either fresh water (*e.g.*, ponds, lakes, streams), or salt water (*e.g.*, marine, estuaries) type (*Fig. 3.1*). An ecosystem may be as small as drop of pond water. Such a small ecosystem is called **micro-ecosystem**. It may be as large as an ocean. Ecosystems are so varied in form and structure, that whatever has a distinct community of its own, can be called an ecosystem, *e.g.*, a crop field, park, laboratory culture, grassland etc.

Human activities may modify or convert natural ecosystems into **man-made** or **anthropogenic ecosystems**. Cutting of forests and the conversion of land for tree plantations or agricultural systems, construction of dam often resulting into submergence of forests and formation of water reservoirs, are some examples of conversion of natural ecosystems into man-made ecosystems. Spacecrafts and aquariums may also be considered as man-made ecosystems. This chapter deals with the basic concepts of ecosystem structure and function related to productivity, energy flow, decomposition, ecological efficiencies, nutrient cycling and the general characteristics of terrestrial biomes.

ECOSYSTEM

- **Natural Ecosystem**
  - **Terrestrial** (Forest, Grassland, Desert)
  - **Aquatic**
    - **Fresh Water**
      - **Lentic** (Standing water) (Lake, Pond, Ditch, Swamp)
      - **Lotic** (Running water) (River, Spring, Stream)
    - **Marine** (Ocean, Sea)
- **Artificial Ecosystem** (Man-engineered ecosystem, *viz.*, Crop, Urban, Industrial, Laboratory, Space)

Fig. 3.1. Types of ecosystems.

ECOSYSTEM COMPONENTS

An ecosystem consists of two types of components—**biotic** and **abiotic**. The biotic components include all types of living beings. They are often distinguished into **autotrophs** and **heterotrophs**. Heterotrophs are of two types—**consumers** (herbivores and carnivores) and **decomposers**. Different biotic components are connected through food and other relations. Food is synthesized from inorganic raw materials by the autotrophs only. Therefore, autotrophs are called **producers**. The abiotic components include non-living substances and physical factors of the environment.

Biotic Components

1. Producers

These are generally chlorophyll bearing autotrophic (= self nourishing) organisms which prepare organic compounds from inorganic raw materials with the help of sunlight through the process of photosynthesis. 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 called **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.

During photosynthesis autotrophs convert solar energy into chemical bond energy of the organic compounds. Producers are, therefore, called **convertors** or **transducers**. The organic compounds synthesised by the producers are utilized in their body building and liberation of energy for various activities. Heterotrophs depend upon the producers for their food and energy requirements.

2. Consumers

Comsumers or phagotrophs (phago = to eat) are heterotrophic (= other feeding) organisms, mostly animals, which generally ingest and swallow their food. The food of consumers consists of organic compounds produced by other living organisms. Consumers are of two types—herbivores and carnivores.

(*i*) ***Herbivores*** feed directly on plants. They are also called first order consumers. For example, grasshopper, deer, rabbits, goat, cattles etc. are some herbivores of a terrestrial ecosystem. Protozoans, molluscs, crustaceans etc. are some herbivores of an aquatic ecosystem. **Elton** (1927) called primary consumers as **'key industry animals'**, because they convert the plant material into animal material.

(*ii*) ***Carnivores*** are animals which feed or prey upon other animals. The carnivores which feed upon herbivores are called *primary carnivores* or *second order consumers e.g.* frog, birds, fox, cat etc. The animals which feed upon the primary carnivores are called *secondary carnivores or third order consumers e.g.* owl, peacock, tiger, lion etc. Secondary consumers are preyed upon by some larger carnivores. They are called *tertiary consumers* and so on. The larger carnivores such as lion, tiger etc. which cannot be preyed upon further, occupy top position in the food chain and are called *top carnivores*.

3. Decomposers

These are saprophytic (sapro = to decompose) micro organisms such as bacteria and fungi, which obtain their food from dead bodies of producers (plants) and consumers (animals) and their organic wastes. Decomposers are often called **micro-consumers** because of their small size. They are also called **reducers** because they decompose and remove the dead bodies of the organisms.

Decomposers secrete digestive enzymes in the surrounding medium to digest the organic material (extracellular digestion). They absorb a part of the decomposition products for their own nourishment. The remaining substances add materials and minerals to the substratum. This process is called **mineralization**. The released minerals are reutilized as nutrients by the producers.

> **Parasites and Scavengers**
>
> Two more categories of living organisms are also recognised in the ecosystem by some workers. They are parasites and scavengers (detritivores). Parasites obtain food directly from other organisms called hosts. Parasites belong to all categories of organisms *e.g.* bacteria, fungi, protozoans, worms etc. Scavengers are animals which feed on the dead bodies of other organisms *e.g.*, termites, beetles, worms etc.

An ecosystem is not an isolated unit as it often held. Ecosystems often integrade with each other. At large spatial scale all ecosystems are interconnected by flow of energy and transfer of materials with the neighbouring ecosytems, or even with distant ecosystems. For example, leaves of river-bank trees falling in river water represents transfer of energy and material from terrestrial to aquatic ecosystem. Similarly, terrestrial birds diving to catch fishes in water bodies make similar transfers from aquatic to terrestrial ecosystems. Soil eroded from a forest ecosystem with flowing water may deposit over other ecosystem, dust blown from a desert ecosystem may deposit over another ecosystem located far away, are some other common examples of transfer of energy and material from one ecosystem to another. Thus, the whole earth is considered to be an ecosystem, which is referred as **biosphere** or **ecosphere**.

Abiotic (non-living) Components

Structurally abiotic components include:

(*i*) ***Climate Regime.*** Precipitation, temperature, light and other physical factors.

(*ii*) ***Inorganic Substances.*** Elements such as C, N, H, O, P, S, etc., involved in material cycles.

(*iii*) ***Organic Substances.*** Carbohydrates, proteins, lipids and humic substances that link the abiotic components with the biotic components.

The minerals and atmospheric gases keep on cycling. They enter into biotic systems and after the death and decay of organism return to the soil and the atmosphere. This is known as **biogeochemical cycle.** This circulation of materials involves trapping of the solar energy by the green plants, which is ultimately lost by the organisms in several ways. The amount of abiotic materials present in an ecosystem is called **standing stage.**

ECOSYSTEM—STRUCTURE AND FUNCTION

Structure

The structure of an ecosystem is characterised by the physical organisation of biotic and abiotic components. The major structural features of ecosystem are : species composition, stratification, trophic organisation and nutrients.

1. **Species Composition.** Each ecosystem has its own type of species composition. Different ecosystems have different species composition. A great variety of species is found in forest ecosystem, whereas a few species occurs in a desert ecosystem.

2. **Stratification.** The organisms in each ecosystem form one or more layers or strata, each comprising the population of particular kind of species. In some ecosystems, such as tropical rain forests, the crown of trees, bushes and ground vegetation form different strata and are occupied by different species. On the other hand, the desert ecosystem shows a low discontinuous herb layer consisting of fewer and extensive bare patches of soil.

3. **Trophic Organisation.** Food relationships of producers and consumers is another way to depict ecosystem structure. Trophic (food) structure of ecosystem is based on the existence of several trophic levels in the ecosystem. The producers (autotrophs) form the first trophic level or T_1, herbivores the second or T_2 and carnivores constitute the third or T_3.

There may be 2–3 levels of carnivores. The top carnivore belong to T_4 or T_5 trophic levels. Decomposers form the ultimate or detritus trophic level (*Fig. 3.2*). Parasites feed upon the organisms of all trophic levels. Therefore, they do not have a fixed trophic level. Similarly there is no fixed trophic level for omnivorous organisms like man.

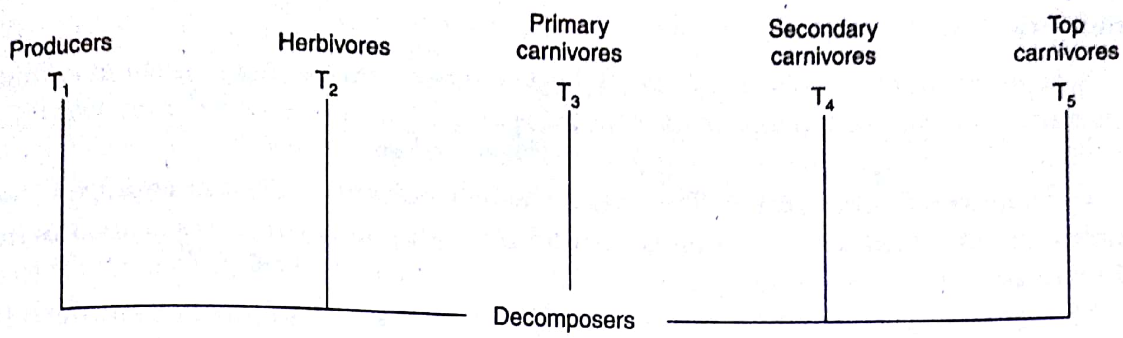

Fig. 3.2. Trophic levels in an ecosystem.

In an ecosystem there can be only 4–5 successive trophic levels, because:

(*i*) All the food available at one trophic level is not eaten by the animals of the next trophic level. Some of the food energy is lost in this manner.

(*ii*) All the food eaten by an animals is not useful, thus a good deal of energy containing food is passed out as waste.

(*iii*) A large amount of energy is lost in respiration to derive organism's metabolism, and thus, there is not much energy left to support higher trophic levels.

Trophic structure may also be described in terms of the amount of living material present in different trophic levels. The amount of the living material present in different trophic levels at a given time is called **standing crop.** It is commonly expressed as the number or biomass of organisms per unit area. The biomass of a species may be expressed in terms of either fresh or dry weight. But, generally dry weight is preferred so that the variations in weight due to seasonal moisture differences in biomass can be avoided.

4. **Nutrients.** In each ecosystem, the nutrients necessary for the growth of living organisms are accumulated in the biomass and the abiotic components like soil. The amount of nutrients such as nitrogen, phosphorus and calcium present in the soil at any given time is termed as **standing state.** Different ecosystems have different standing state of nutrients. The standing state of nutrients may vary at different time even in the same ecosystem.

Function

Ecosystems have some functional attributes which keep the component parts running together. Each ecosystem possesses a natural tendency to persist. Various functions performed by the structural components of the ecosystem ensure persistance of the system. For instance, green leaves prepare food and roots absorb nutrients from the soil. Herbivores feed on 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. All these functions in the ecosystem occur through delicately balanced and controlled processes. For example, food production in plants is carried out by the process of photosynthesis, nutrients contained in the organic matter are released through the process of decomposition. A knowledge of the rates of different processes at which they occur in the ecosystem is necessary to understand the interrelations, structure and functions of the ecosystem. The major functional attributes of the ecosystem are : (*i*) Productivity and decomposition (*ii*) Energy flow (*iii*) Nutrient cycling (*iv*) Development and stabilization.

Productivity

A constant input of solar energy is the basic requirement for any ecosystem to function and sustain. The rate of organic matter or biomass production is called productivity. The productivity of an ecosystem is of two types : primary and secondary.

(i) ***Primary Productivity.*** The rate at which radiant energy is captured by the producers for the synthesis of organic compound through photosynthesis is called **primary productivity.** It is expressed as g m^{-2} $year^{-1}$ for dry matter and kcal m^{-2} $year^{-1}$ for energy.

The primary productivity is further distinguished as **gross primary productivity** or **GPP** (the rate of total capture of energy or the rate of total production of organic matter/biomass by the producers per unit area and time) and **net primary productivity** or **NPP** (*the rate at which energy or organic matter stored by the producers after respiration and maintenance per unit area and time*). Net primary productivity is the balance energy or biomass left after meeting the cost of respiration and maintenance of producers.

Net primary productivity (NPP) = Gross primary productivity (GPP)
– Loss due to respiration and maintenance (R).

The net primary productivity is the available biomass for the consumption to heterotrophs (herbivores and decomposers).

(ii) ***Secondary Productivity.*** The rate of resynthesis of organic matter by the consumers is known as secondary productivity. It depends upon the loss while transferring energy containing organic matter from the previous trophic level plus the consumption due to respiration. The respiration loss is about 20 per cent for autotrophs, 30 per cent for herbivores and upto 60 per cent in case of carnivores. Therefore, net productivity decreases with each trophic level.

Magnitude of Primary Productivity. The magnitude of primary productivity depends on the photosynthetic capacity of producers and the prevailing environmental conditions, particularly solar radiation, temperature and soil moisture. Therefore, it varies in different types of ecosystem. The annual net primary productivity of the whole biosphere is approximately 170 billion tons (dry weight) of organic matter. Previously, 90% of the productivity of the whole biosphere was believed to be due to oceans. But according to new estimates, oceans contribute only 32% of the total (*i.e.*, 55 billion tons out of 170 billion tons).

Wittaker (1970) and **(Lieth)** (1974), have compiled data about the net productivity of major ecosystems of the world (*Fig. 3.3*). The net productivity of the land is about 11.5×10^{10} tons/yr (total land area 149×10^6 km^2). The average or mean value is 7.7 ton/ha/yr (770 gm/m^2/yr). The net productivity of the oceans is about 5.5×10^{10} tons/yr (with a total area of 361×10^6 km^2) with an average value of 1.55 ton/ha/yr (155 gm/m^2/yr). The total annual production comes to about 17.0×10^{10} tons (170 billion tons).

Maximum productivity occurs in coral reefs, followed by estuaries and sugar cane fields. On land, the maximum primary production rate is found in tropical rainforests followed by tropical deciduous forests, temperate forests, savannah, temperate grasslands and desert shrub (*Table 3.1*).

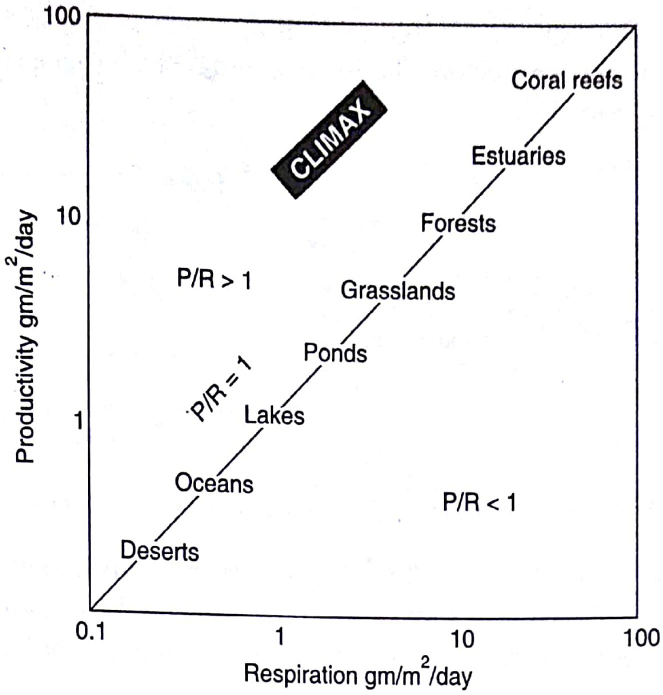

Fig. 3.3. Magnitude of primary production in various ecosystems and climatic regions.

Table 3.1. ***Occupied Geographical Area, Mean Plant Biomass and Net Productivity in World's Major Ecosystem***

Ecosystems	*Area (10^6 km^2)*	*Mean Plant Biomass (t ha^{-1})*	*Mean Net Primary Productivity (t ha^{-1} year^{-1})*
Tropical rainforest	17	440	20
Tropical deciduous forest	8	360	15
Temperate deciduous forest	7	300	12
Temperate coniferous forest	12	200	8
Savannah	15	40	9
Temperate grassland	9	20	5
Desert shrub	18	10	0.7

t = ton = 1000 kg, ha = hectare = 1000 m^2.

Decomposition

It is the process by which complex organic materials are broken down by the decomposers to inorganic raw materials like carbon dioxide, water and various nutrients. In an ecosystem, upper layer of soil is the main site of decomposition. The organic materials involved in decomposition include dead plant parts and animal remains, called **detritus.** It is of two types—(*i*) **above ground detritus** (leaf litter, dried plant parts, remains of animals, their droppings and excretions), (*ii*) **below ground detritus** (mainly dead roots, also underground dead animals).

Decomposition Process. A number of soil organisms, bacteria, fungi, protozoa, mites, earthworms, snails, millipedes, centipedes, insects and nematodes play important role in decomposition. The earthworms often referred to as the 'farmer's friend' because they help in the breakdown of complex organic matter as well as in loosening of the soil. A number of processes are involved in decomposition. They are grouped into three categories, all of which operate simultaneously (*Fig. 3.4*).

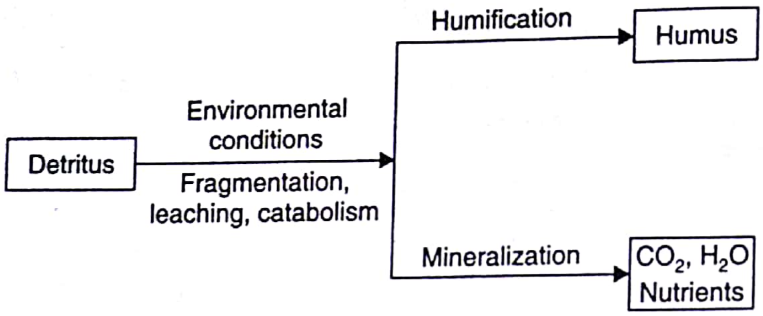

Fig. 3.4. Processes involved decomposition of detritus.

(*i*) ***Fragmentation of Detritus.*** The detritus feeding organisms called **detritivores** (*e.g.,* termites, carrion beetles, earthworms etc.). They feed on detritus and break it down into small pieces. It increases the surface area of the detritus for microbial action. The detritus also get pulverized, when passed through the digestive tracts of detritivores as a part of detritus comes out undigested. The part of detritus digested by detritivores is immobilized.

(*ii*) ***Catabolism.*** The decomposers (*e.g.,* bacteria, fungi) secrete digestive enzymes and convert the complex insoluble organic compounds into simple and soluble organic and inorganic substances. A part of the broken down food is taken up by the decomposers and immobilized.

(*iii*) ***Leaching.*** The soluble substances formed during decomposition are subjected to passage to deeper layers of soil, along with percolating water. It is called leaching.

Humification and Mineralization. Two products, **humus** and **inorganic nutrients** (= minerals) are formed as a result of decomposition (*Fig. 3.5*). The processes involved in their formation are called **humification** and **mineralization** respectively. Humus is dark coloured amorphous organic matter, rich in lignin and cellulose. It is colloidal in nature. It is quite resistant to microbial action and undergoes extremely slow decomposition. It serves as a reservoir of nutrients and helpful in maintenance of soil moisture as well as aeration. The nutrients present in the humus are released slowly as the latter undergo slow decomposition. Mineralization results in the release of inorganic substances (*e.g.,* CO_2, water) and nutrients (*e.g.,* NH_4^+, Ca^{2+}, Mg^{2+}, K^+ etc.) in the soil. The organisms that decompose fresh organic matter are ecologically different flora from those that decompose humus.

Nutrient Immobilization. Some soil nutrients are held up in the biomass of decomposers and detritivores, and become temporarily unavailable to other organisms. Such incorporation of soil nutrients in decomposer microbes and detritivores is called **nutrient immobilization.** The soil nutrients may remain immobilized for variable periods. Immobilization is a useful process as it prevents nutrients from being washed out from the ecosystem. The immobilized nutrients are released into the soil and become available to the other organisms only after the death of decomposers and detritivores.

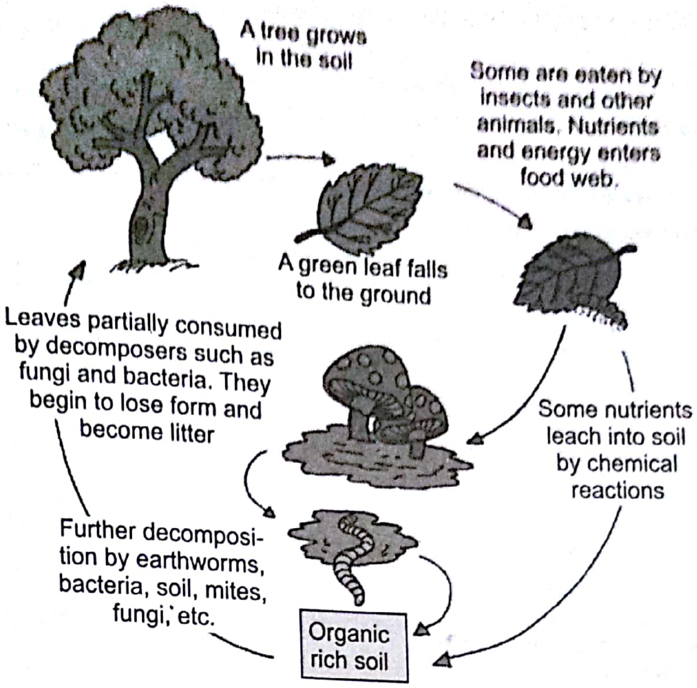

Fig. 3.5. Schematic representation of decomposition cycle in a terrestrial ecosystem.

Factors affecting Decomposition. The rate of decomposition of detritus depends upon chemical quality of detritus, temperature, soil moisture and soil pH. (*i*) In a particular climatic condition, decomposition rate is slower, if detritus is rich in lignin and chitin, and quicker, if detritus is rich in nitrogen and water soluble substances like sugars. (*ii*) Temperature and soil moisture are the most important climatic factors that regulate decomposition through their effects on the activities of soil microbes. Warm and moist environment favour decomposition, whereas low temperature and dry environment decrease the rate of decomposition. (*iii*) Decomposition is oxygen requiring process, absence of oxygen (anaerobiosis) inhibits decomposition and results in pilling up of detritus. (*iv*) Neutral and slightly alkaline soils are rich in detritivores, earthworms and decomposer microbes, hence show quick decomposition. Acidity decreases the number of decomposer organisms and thus, the process of decomposition.

Energy Flow

The functioning of ecosystem depends on the flow of energy through matter. Energy enters the ecosystem from the solar radiations and is converted into chemical form by the producers. From there the energy passes from one trophic level to the next through food. The flow of energy, in the ecosystem is governed by two basic laws of thermodynamics *i.e.*, (*i*) energy can neither be created nor destroyed, but can be transformed from one state to another, or transferred from one component to another. (*ii*) every transformation or transfer of energy is accompanied by its dispersion. Therefore, one hundred per cent transformation of energy from one form to the other or transfer from one organism to the other is not possible. It is always accompanied by some dispersion or loss of energy in the form of heat.

Except for the deep sea hydrothermal ecosystem, sun is the only source of energy for all ecosystems on earth. Solar energy is considered to be a dilute low quality energy. It increases in quality on passing through each stage of concentration in food-chain.

Of the incident solar radiation, less than 50 per cent of it is 'Photosynthetically Active Radiation (PAR)'. About 1–5 per cent of the incident solar radiation or 2–10 per cent of PAR is captured by the photosynthetic organisms for the synthesis of organic matter. About 20 per cent of it is consumed in respiration, so that net capture of energy or net primary productivity is 0.8–4 per cent of incident radiation or 1.6–8 per cent of PAR (Fig. 3.6). Its value is 1.15 per cent in grasslands, 0.9 per cent in Savannah, 0.81 per cent in mixed forests, 5 per cent in crops and 10–12 per cent in sugarcane crop.

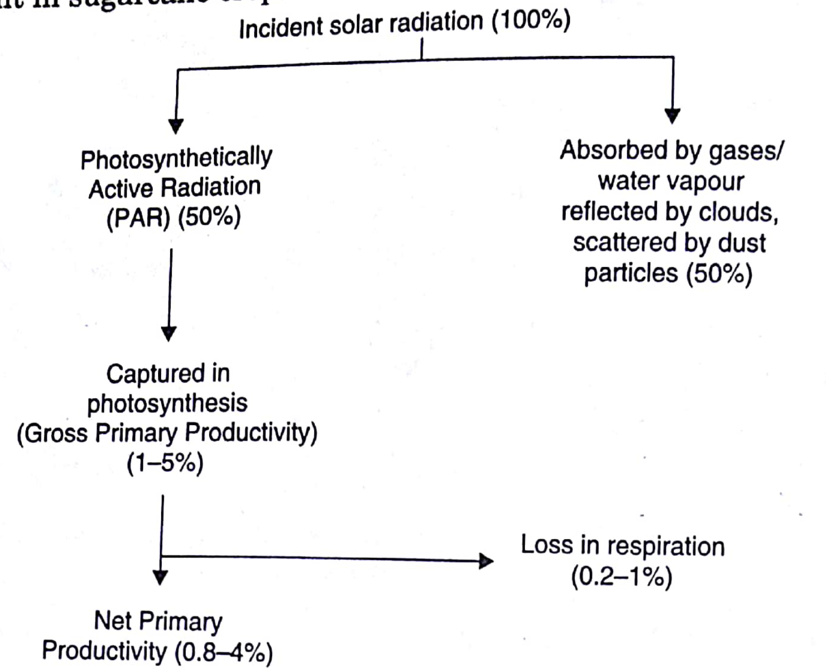

Fig. 3.6. Fate of solar radiation incident on plant canopy (values in parenthesises represent fraction of incident solar radiation).

The entire world is sustained by the small amount of energy *i.e.*, 2–10 percent of PAR captured by the photosynthetic organisms. It is very important to know how the solar energy captured by photosynthetic organisms flows through different organisms of an ecosystem. All heterotrophic organisms are dependent for their food on producers, either directly or indirectly. Energy does not remain trapped permanently in any organism. It is either passed onto higher trophic level or becomes available to detritivores and decomposers when the organism dies.

There are two aspects with respect to energy flow in ecosystem.

(*i*) There is unidirectional or one way flow of energy in the ecosystem *i.e.*, from producers through herbivores to carnivores. The energy cannot be transferred in the reverse direction. *i.e.* the energy that is captured by the autotrophs does not revert back to solar input ; or the energy which passes to the herbivores does not pass back to the autotrophs.

(*ii*) The amount of energy flow decreases with successive trophic levels. Producers capture only a small fraction of solar energy (1-5% of total radiation) and the bulk of unutilized energy is dissipated mostly as heat. Part of energy captured in gross production of producers or gross primary production (GPP) is used for maintenance of their standing crop (respiration) and for providing food to herbivores (herbivory). The unutilized net primary production (NPP), 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 secondary productivity (SP) is approximately 10% of the gross primary productivity (GPP) or the gross productivity of producers.

The energy assimilated by the herbivores is used in respiration and a fraction of unassimilated energy is transferred to decomposers (*e.g.*, feacal matter). The herbivore level of energy either utilized by the carnivores or gets transferred to decomposers after the death of herbivores. In this way, again only a small fraction *i.e.* about 10% of herbivore productivity is used to support carnivore productivity. In the same way, the energy available at carnivore trophic level is again divided, leaving a very small fraction to support the next trophic level *i.e.*, top carnivore.

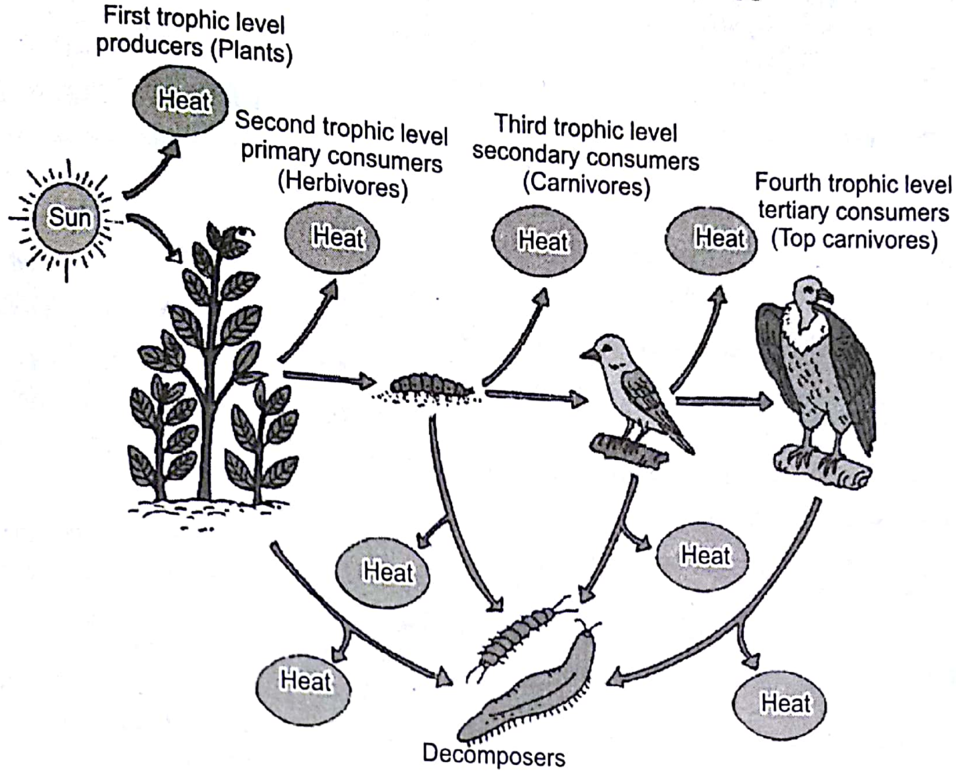

Fig. 3.7. Diagrammatic representation of energy flow through different trophic levels.

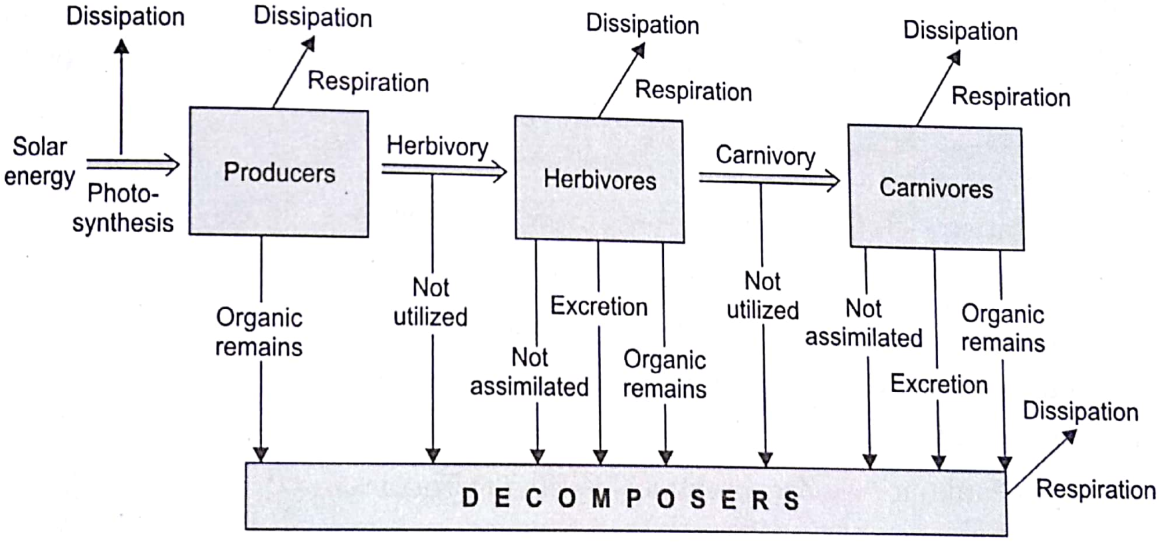

Fig. 3.8. Flow of energy in ecosystem.

With increasing trophic levels, the respiration cost also increases sharply. On an average, producers consume about 20% of their gross productivity in respiration. The herbivores consume about 30% of assimilated energy in respiration. In carnivores, the proportion of assimilated energy consumed in respiration rises to about 60%. Thus, there is a tremendous loss of energy at successive higher trophic levels. As a result, the residual energy is decreased to such an extent that no further trophic level can be supported. Therefore, there can be 3–5 trophic levels in the food chains of an ecosystem.

FOOD CHAIN AND FOOD WEB

Food Chain

In the ecosystem various trophic levels are connected through food chain. *The transfer of food energy from the source in plants through a series of organisms with repeated eating and being eaten is referred to as a food chain. Or The transfer of energy from one trophic level (e.g., producers) to the next trophic level (e.g., consumers) is called food chain.* All types of ecosystems possess two types of food chain ; grazing food chain and detritus food chain.

1. **Grazing Food Chain (GFC).** It extends from producers through herbivores to carnivores. Producers are autotrophic organisms which synthesise organic food from simple inorganic raw materials through photosynthesis utilizing solar energy. A part of the food synthesised by the producers is used in their body building, while the rest is utilized in providing energy for various life activities.

The animals that feed on other organisms are called consumers. The consumers which directly take their food from plants are called herbivores or first order consumers. *e.g.*, zooplanktons, small fish, grass-hopper, field mouse, rabbit, deer, goat, elephant etc. A part of the plant food eaten by herbivores become constituent of their body, while major part is utilized by them in production of energy for various life activities. The herbivores are eaten by second order consumers or primary carnivores. *e.g.*, frog, some birds, fishes, wild cat, fox etc. A part of flesh or food obtained from herbivores is used in body building by the primary consumers, while the rest is consumed in providing energy for various life activities. The larger **carnivores** prey upon the primary carnivores are called third order consumers or **secondary carnivores.** *e.g.*, Snake (prey upon frog), wolf (prey upon fox). The last order consumers are not preyed upon by other animals. They are called top carnivores. *e.g.*, shark, crocodile, tiger, lion etc.

Some common food chains are given below.

Terrestrial Food Chains

(*i*) Vegetation ⟶ Grasshopper ⟶ Shrew ⟶ Hawk.

(*ii*) Vegetation ⟶ Rabbit ⟶ Fox ⟶ Wolf ⟶ Tiger.

(*iii*) Vegetation ⟶ Frog ⟶ Snake ⟶ Peacock.

(*iv*) Plant ⟶ Butterfly ⟶ Frog ⟶ Snake ⟶ Hawk. (*Fig. 3.9*)

Aquatic Food Chains

(*i*) Phytoplankton ⟶ Zooplankton ⟶ Small Crustaceans

⟶ Predator insects ⟶ Small fish ⟶ Larger fish ⟶ Crocodile
Small fish ⟶ Stork/King fisher

(*ii*) Phytoplankton ⟶ Zooplankton ⟶ Small fish ⟶ Larger fish ⟶ Shark.

(*iii*) Phytoplankton ⟶ Zooplankton ⟶ Fish ⟶ Crane ⟶ Hawk. (*Fig. 3.9*)

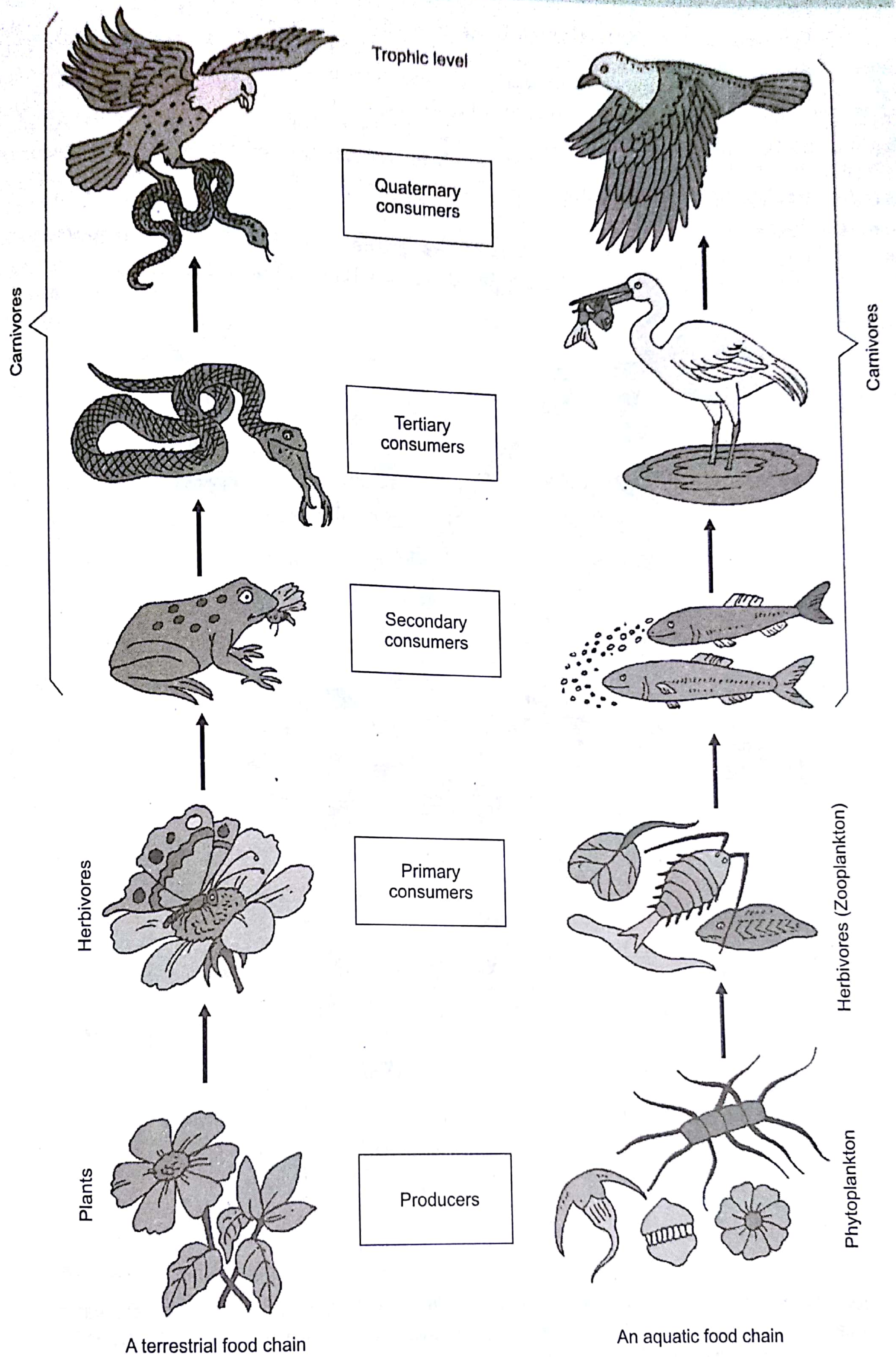

Fig. 3.9. Food chains and trophic levels in terrestrial and aquatic ecosystems.

2. Detritus Food Chain (DFC). It starts with dead organic matter and passes through detritus feeding organisms in soil to organisms feeding on detritus feeders and their predators, *e.g.* decomposition of accumulated litter in forests. The ecosystems exhibiting detritus food chain are thus less dependent on direct solar energy. These depend chiefly on the influx of organic matter produced in another system. In fact, detritus food chain is simply a sub-component of another ecosystem. A much larger fraction of energy flows through the detritus food chain. A good example of a detritus food chain based on mangrove leaves is described below.

Mangrove leaves ⟶ Detritus ⟶ Microorganisms ⟶ Crabs and shrimps ⟶ Small fishes ⟶ Large fishes. (*Fig. 3.10*)

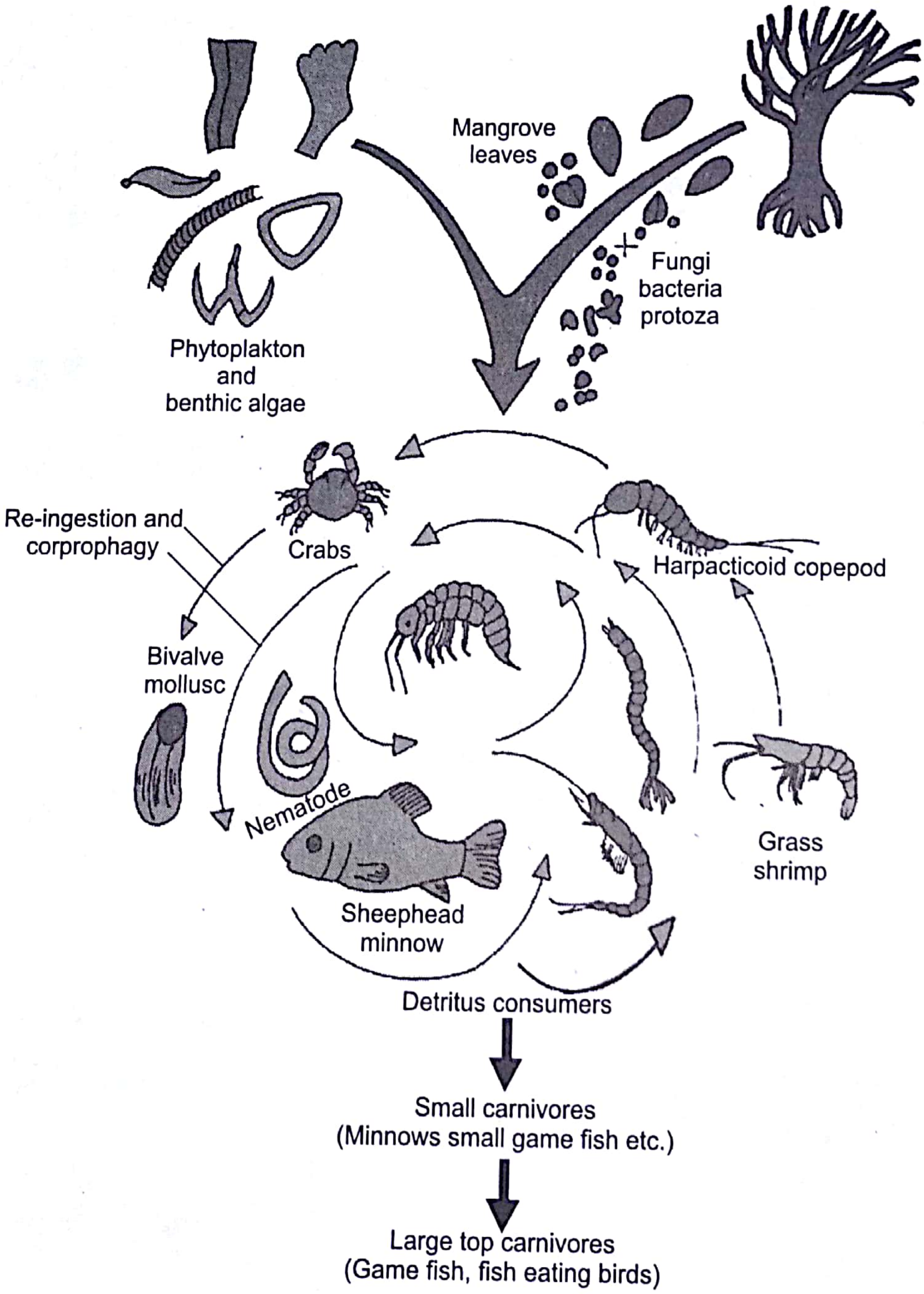

Fig. 3.10. A detritus food chain based on mangrove leaves falling into shallow estuary waters. Leaf fragments acted on by saprotrophs and colonised by algae are eaten and re-eaten by detritivores which in turn, provide the main food for game fish, herons and storks.

Food Web

In nature, the food chains are not isolated sequences but are rather interconnected with one another. '*A network of food chains which are interconnected at various trophic levels, so as to form a number of feeding connections amongst different organisms of a biotic community is called food web*' (*Fig. 3.11 and 3.12*). A food web opens several alternate pathways for the flow of food energy. It also allows an organism to obtain its food from more than one type of organisms of the lower trophic level. Thus, a field mouse may be eaten by a wild cat, a snake or an owl. Similarly, wild cat eats a number of herbivores like birds, mice, squirrels etc. A wolf or jackal can eat both rabbit and deer.

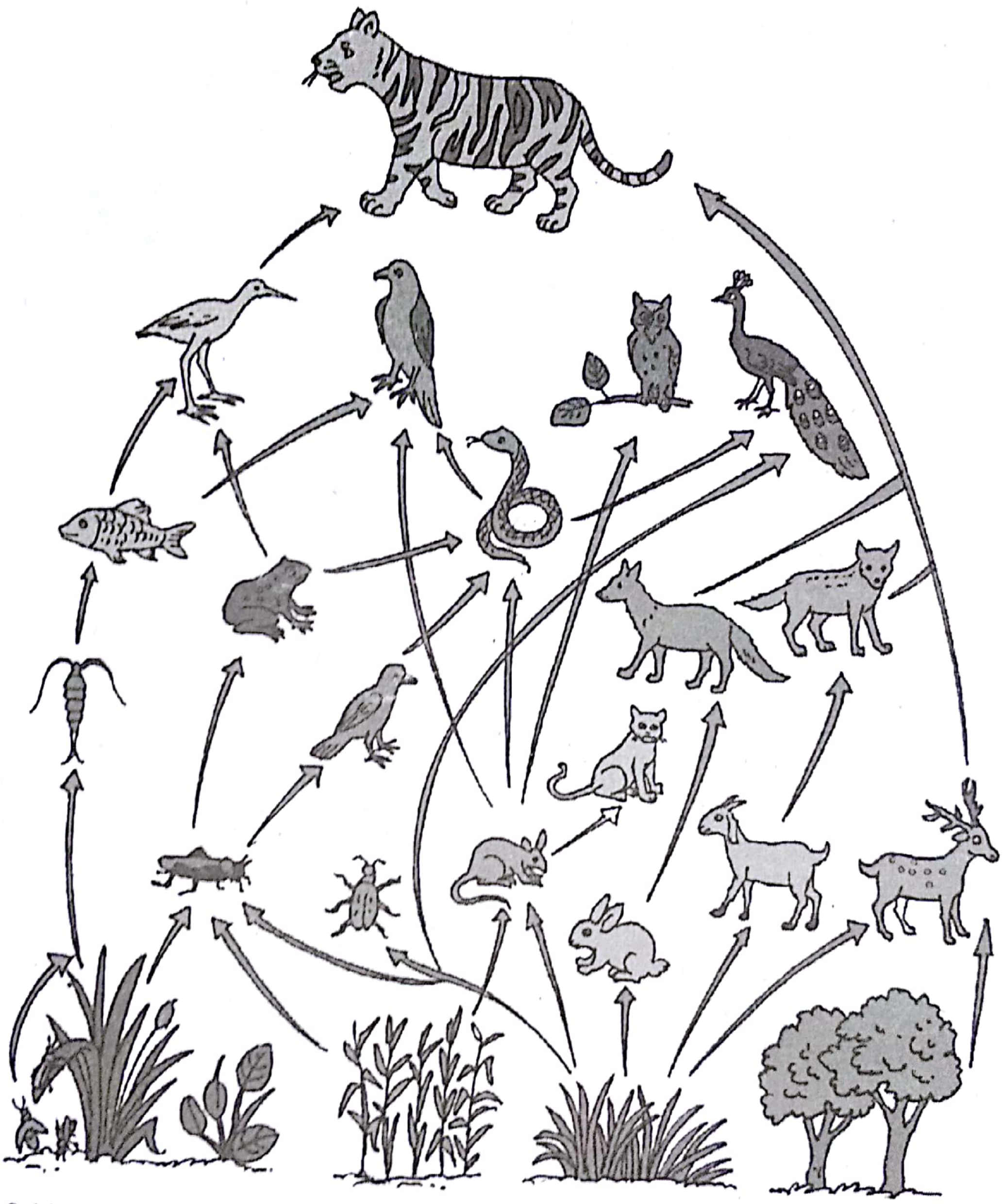

Fig. 3.11. A food web shows the main food links and interconnection of many food chains. An organism may form a food source for many other organisms, thus forming a web.

Generally, a food web operates according to taste and food preferences of the organisms at each trophic level, yet availability of food source and other compulsions are equally important. For example, tigers normally do not eat fish or crabs, but in Sunderbans, they are forced to feed on them in absence of their natural prey.

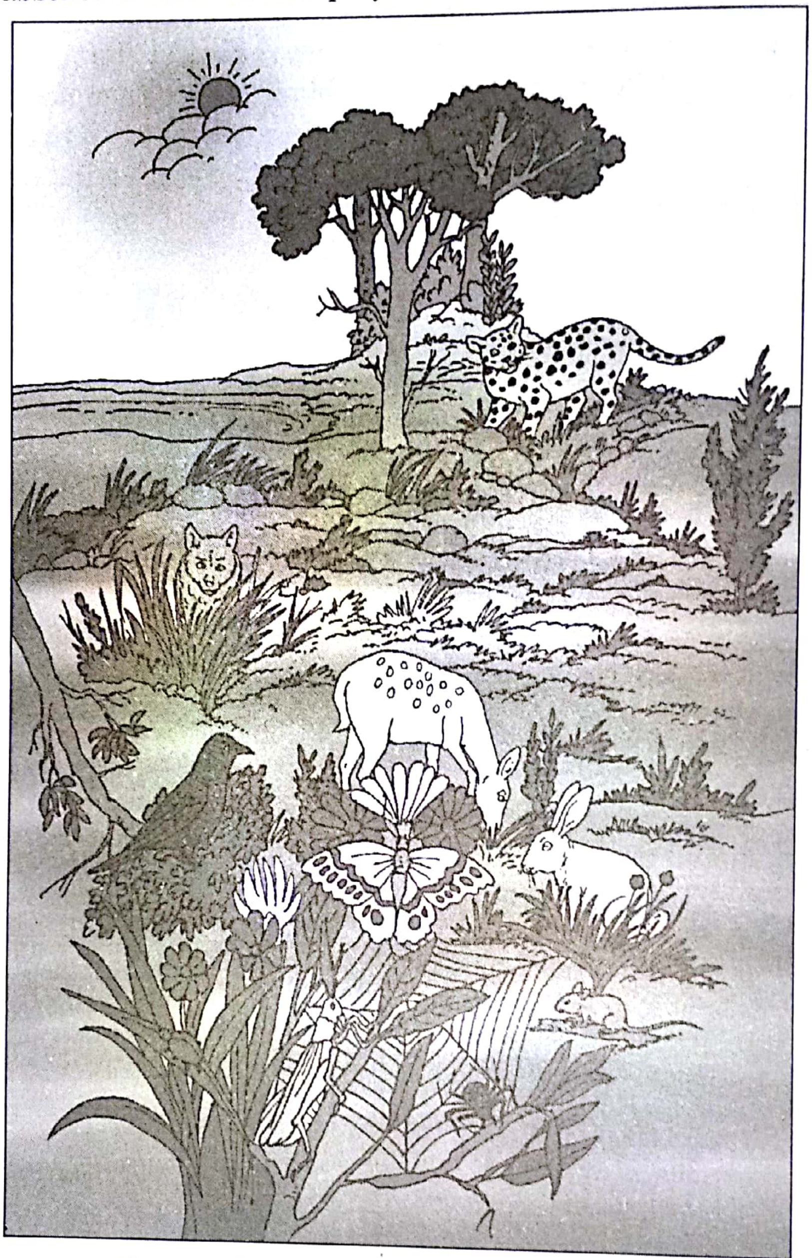

Fig. 3.12. Food web and energy cycle in nature.

ECOLOGICAL PYRAMIDS

In an ecosystem, trophic structure can be represented by comparing standing crop (either number of individuals or biomass) or energy fixed per unit area at different trophic levels.

When the ecological parameters such as number of organisms, biomass or energy at successive trophic levels are plotted, they assume a shape of pyramids. Thus, *an ecological pyramid is a graphic representation of an ecological parameter like number of individuals or* *amount of biomass or amount of energy present in various trophic levels of a food chain with producer forming the base and top carnivores the tip.* Ecological pyramids were first devised by a British ecologist **Charles Elton** (1927) and are, therefore, also called **Eltonion pyramids.** In a pyramid, various steps of food chain are represented sequence wise with producers at the base, herbivores above them, followed by primary carnivores and so on, with top carnivores at the top (*Fig. 3.13*).

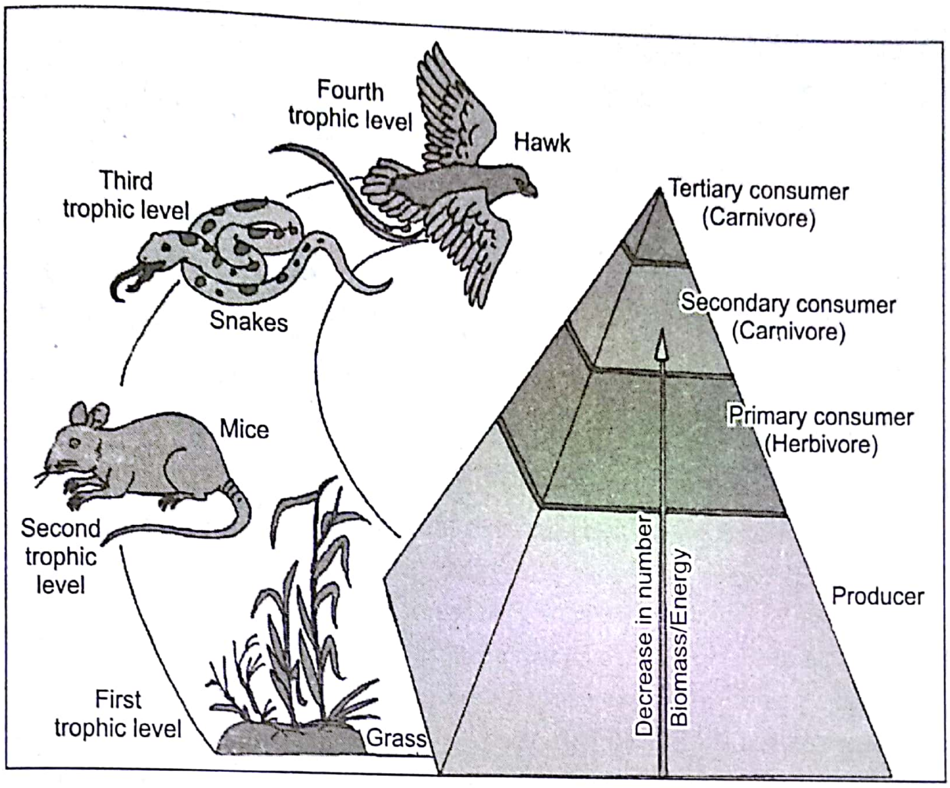

Fig. 3.13. Formation of an ecological pyramid.

An ecological pyramid can be upright (with larger base and gradually tapering towards the tip), inverted (narrow base and gradually becoming broader towards the tip) or spindle-shaped (narrow both at base and tip with broader part in the middle). There are three important parameters of each tropic level in a food chain *i.e.,* number of individuals, amount of biomass and amount of energy. Accordingly, three types of ecological pyramids are recognised—pyramid of numbers, pyramid of biomass and pyramid of energy.

Pyramid of Numbers

A graphic representation of number of individuals per unit area of various trophic level stepwise with producers forming the base and top carnivores the tip is called pyramid of numbers. It indicates the numerical relationship between different trophic level of the food chain. Mostly the pyramid of number is straight or upright with number of individuals in successive higher tropic levels goes on decreasing from base to apex. The maximum number of individuals occur at the producers level. They support a small number of herbivores. The herbivores, in turn, support a fewer number of primary carnivores and so on. Top carnivores are very few in number.

For example, in a grassland, a large number of grass or herbs support a lesser number of grasshoppers, the latter support fewer number of frogs, and the frogs to still smaller number of snakes, the latter support to very few peacocks or falcons. Similarly, in a pond ecosystem, a large number of phytoplankton support a lesser number of zooplankton followed by carnivores—fishes and top carnivores like stork or kingfisher (*Fig. 3.14*).

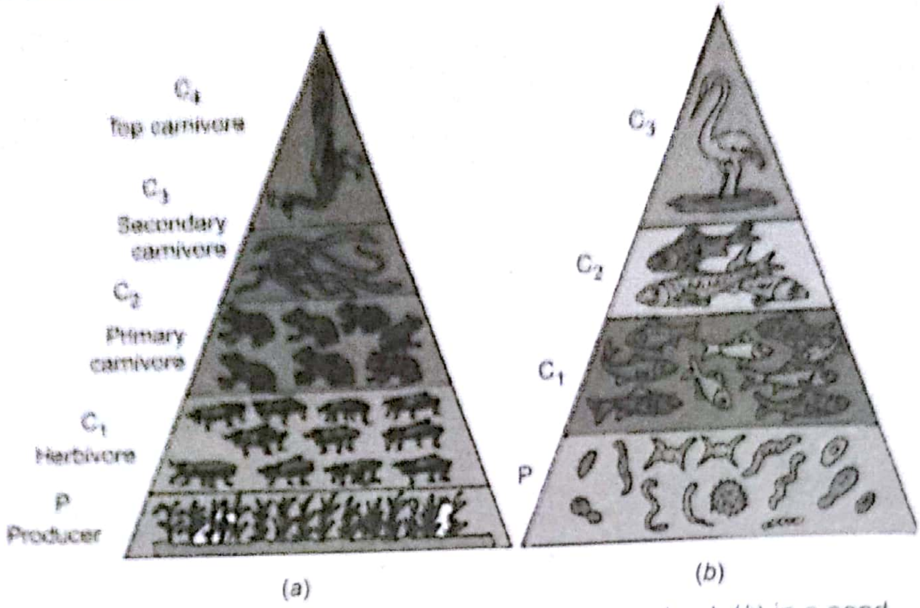

Fig. 3.14. Upright pyramids of numbers. (*a*) in a grassland. (*b*) in a pond.

In a food chain, the organisms of higher tropic level are dependent for food and energy on the organisms of lower trophic level. At each trophic level about 90% of the food is wasted or consumed up in respiration and only about 10% is transferred to the higher trophic level. Therefore, the number of individuals in the successive trophic levels decreases from base to the tip, and the shape of the pyramid is upright. In a tree ecosystem an inverted pyramid is obtained. A large tree provides food to several herbivorous birds. The birds support still larger population of ectoparasites (*Fig. 3.15 (a)*). A spindle-shaped pyramid is formed, when a large tree supports, large number of herbivorous birds. The birds are, in turn, eaten by carnivorous birds like falcon or eagle, which are smaller in number (*Fig. 3.15 (b)*).

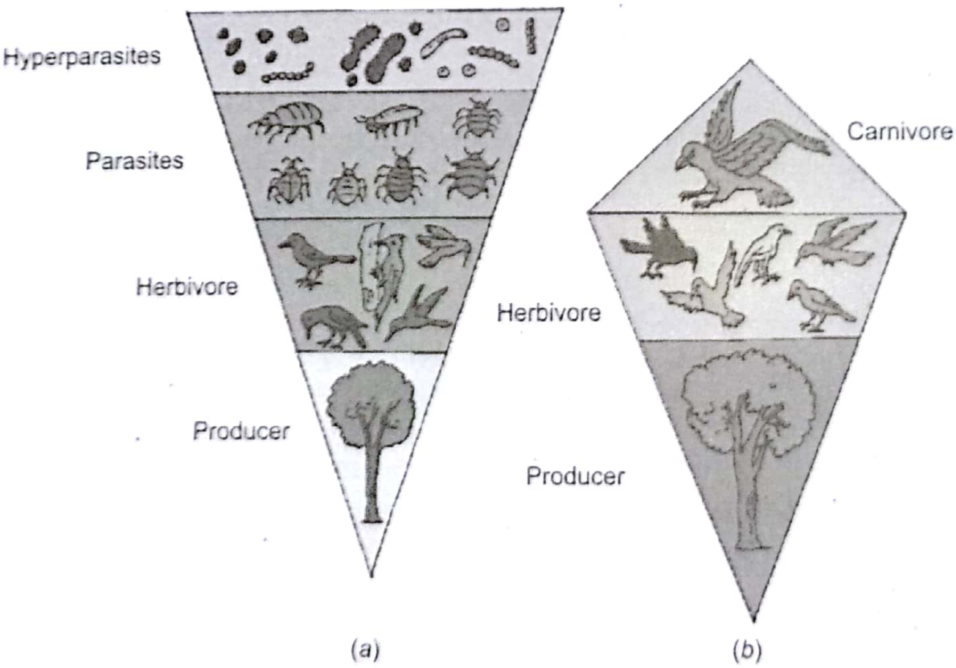

Fig. 3.15. Pyramid of numbers. (*a*) inverted. (*b*) spindle-shaped.

Pyramid of Biomass

The amount of living or organic matter present in a particular environment is called biomass. It is measured both as fresh and dry weight. *A graphic representation of biomass present sequencewise per unit area of different trophic levels, with producers at the base and top carnivores at the tip, is called pyramid of biomass.* In a terrestrial ecosystem, the maximum biomass occurs in producers and there is progressive decrease in biomass from lower to higher tropic levels. It is found that 10–20% of the biomass is transferred from one tropic level to the next in the food chain. Thus 1000 kg of vegetation produces a biomass of only 100 kg of herbivores, which in turn form only 10 kg of biomass of first order carnivores, that give rise just 1 kg of biomass of second order carnivores and so on (*Fig. 3.16* (*a*)). Thus, a vegetarian diet can support a larger population than a non-vegetarian (meat) diet.

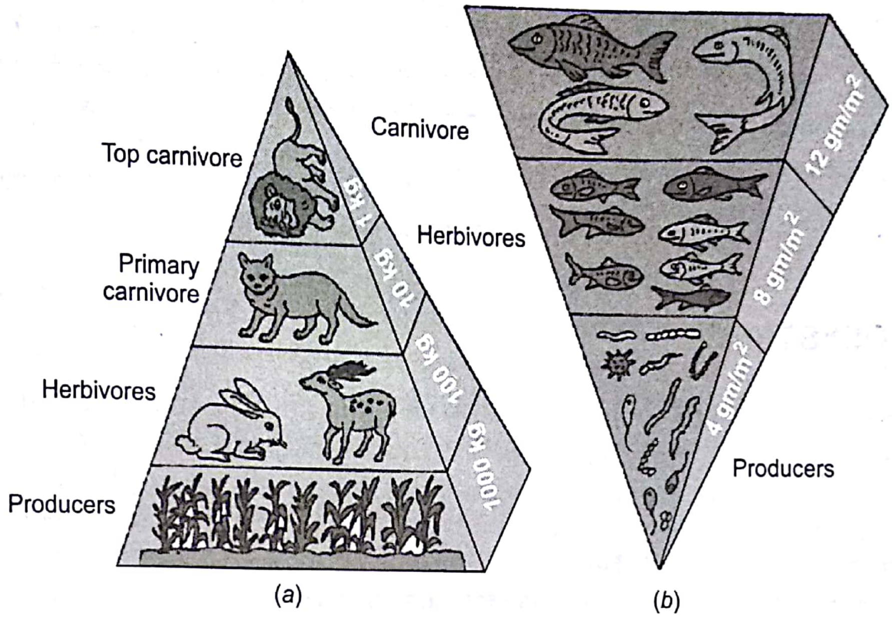

Fig. 3.16. Pyramids of biomass. (*a*) upright pyramid in a terrestrial ecosystem. (*b*) inverted pyramid in an aquatic ecosystem.

In an aquatic habitat the pyramid of biomass is inverted or spindle-shaped, where the biomass of trophic level depends upon the reproductive potential and longivity of the member. Biomass is high only in case of long lived organisms. Thus, the biomass of photoplanktons is less than that of zooplanktons. It is still more in the primary consumers and so on (*Fig. 3.16* (*b*)).

Pyramid of Energy

A graphic representation of the amount of energy trapped per unit time and area in different trophic levels of a food chain with producers forming the base and the top carnivores at the tip, is called pyramid of energy. It is always upright, since it takes into consideration the total energy trapped by a tropic level in a unit area and time. The energy content is generally expressed as K cal/m^2/yr or kJ/m^2/yr. Maximum energy content is present in the producers. The energy content decreases as it passes into higher tropic levels, because of its utilization in performing life activities and overcoming entropy as well as dissipation as heat.

According to **Odum** (1971), in a pond ecosystem, phytoplankton trap 31080 kJ/m^2/yr of solar energy. The zooplanktons and other herbivores, which feed upon the phytoplankton possess an energy content of 7980 kJ/m^2/yr. They support primary carnivores (insect, larvae and small fishes) with an energy content of 2100 kJ/m^2/yr. The secondary carnivores (large fishes), which feed upon the primary carnivores have an energy content of 126 $kJ/m^2/yr$ (*Fig. 3.17*).

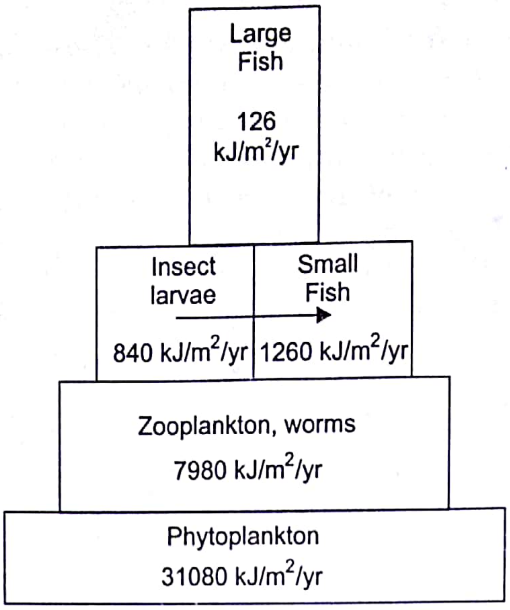

Fig. 3.17. Pyramid of energy in a food chain.

MAJOR ECOSYSTEMS

Different ecosystems like a pond, a lake, a river, a stream, a spring, an estuary, the sea, a forest, grassland, a desert and a cropland are operating as self-sufficient interacting systems in the biosphere. The major ecosystems with their groups of climax plants and associated animals are called biomes. These ecosystem have a more or less similar fundamental plan of their gross structure and function. However, they differ in respect of their species composition and productivity rates. The ecological characteristics of the major ecosystems are described below:

Forest Ecosystem

Forests are natural plant communities with dominance of trees. In India, the forest occupies roughly 19% of the total land area. The major forest biomes found in India are: (*i*) Tropical rain forest (*ii*) Tropical deciduous forest (*iii*) temperate broad leaf forest (*iv*) Temperate needle leaf or coniferous forest.

The different components of forest ecosystems are as follows:

Abiotic Components

These include inorganic and organic substances present in the soil and atmosphere. The climate (temperature, light rainfall etc.) and soil (minerals) vary from forest to forest. In addition to minerals the occurrence of litter is characteristic feature of majority of forests.

Biotic Components

(*i*) ***Producers.*** These are mainly trees that show much species diversity and greater degree of stratification especially in tropical rain and tropical deciduous forests. Besides trees, there are also present shrubs and ground vegetation. In these forests, the producers include the dominant tree species such as *Dipterocarpus, Tectona grandis (Teak), Butea frondosa (Dhak) and Shorea robusta (sal)*. In temperate broad leaf forests several species of *Quercus* (Oak), occur as dominant species, whereas in temperate coniferous forests the dominant trees are *Pinus* (Pine), *Cedrus* (Deodar), *Picea* (Spruce) and *Abies* (Silver fir), etc.

(*ii*) ***Consumers.*** Following types of consumers occur in the forest biomes.

(*a*) *Primary Consumers*. These are the herbivores that include smaller animals feeding on tree leaves as ants, flies, beetles, leaf-hoppers, bugs, spiders, etc., and larger animals grazing on shoots and/or fruits of producers as elephants, neelgai, deer, moles, squirrels, shrews flying foxes, mangooses etc.

(*b*) *Secondary Consumers*. These are the carnivores like snakes, birds, lizards, fox etc., feeding on the herbivores.

(*c*) *Tertiary Consumers*. These are the top carnivores like lion, tiger, etc. that eat upon carnivores of secondary consumer's level.

(*iii*) ***Decomposers.*** These are wide variety of microorganisms including fungi (species of *Aspergillus, Polyporus, Alternaria, Fusarium, Trichoderma*, etc.), bacteria (species of *Bacillus, Pseudomonas, Clostridium*, etc.), and actionmycetes (species of *Streptomyces*). Rate of decomposition in tropical and subtropical forests is more rapid than in the temperate ones.

Importance of Forest in Ecosystems

Forest ecosystem enhances water resources in both quality and quantity, because of their storage capacity and ecological cleansing action. The hydrological cycle depend upon forest ecosystem and encourage absorption rather than run off on precipitation. Forests provide habitat and shelter to wildlife and fishes.

Forest ecosystem is considered as a pathway for the exchange and regulation of atmospheric gases, water and biogenetic nutrients. The forest biomass above ground efficiently intercepts atmospheric particles and aerosols, which are very important to the balance of life on earth.

Grassland Ecosystem

The grassland biomes occur in the regions, where the climate is cool to cold during winters and hot in summers. The different components of a grassland ecosystem are as follows.

Abiotic Components

These include nutrients present in soil and the atmosphere. Thus the elements like C, H, O, N, P, S, etc., are supplied by carbon dioxide, water, nitrates, phosphates and sulphates present in air and soil of the area.

Biotic Components

(*i*) ***Producers.*** The grasslands are characterised by treeless herbaceous plant cover dominated by a wide variety of grass species. The main grasses are species of *Dichanthium, Cynodon, Phragmites, Cenchrus, Imparata* and *Saccharum*, etc. Besides them a few herbs and shrubs also occur as producers.

(*ii*) ***Consumers.*** The various types of consumers occurring in a grassland are as follows:

(a) *Primary Consumers.* The herbivores feeding on grasses are mainly such grazing animals as cows, buffaloes, deer, sheep, rabbit, mouse, etc. Besides them, there are also present some insect species as *Leptocorisa, Dysdercus, Oxyrhachis, Cicindella, Coccinella,* and some termites millipedes, etc. that feed on the leaves of grasses.

(b) *Secondary Consumers.* Snakes, lizards, birds, jackals, fox, etc., are common secondary consumers, which feed on herbivores.

(c) *Tertiary Consumers.* These include hawks, which feed on secondary consumers.

(iii) ***Decomposers.*** Several fungi (*Mucor, Aspergillus, Penicillium, Cladosporium, Rhizopus, Fusarium*, etc.), actinomycetes and bacteria decay the dead organic matter of different forms of higher life. They bring about minerals back to the soil, thus making them available to the producers.

At times grassland ecosystems are burned naturally, probably from fires sparked by lightening. Humans inhabitants start fires intentionally to remove predators, insects for improving the condition of the rangeland. These influences may extend to other components of the grassland ecosystem and increase the vulnerability of the soil erosion, resulting in change in environmental conditions affecting the human and animal life.

Desert Ecosystem

The desert biomes are characterised by extremely low rainfall (less than 25 cm). They occupy about 17% of the land. Due to scarcity of water and high temperature, the biota is poorly represented. The various components of desert biomes are as follows:

Abiotic Components

In desert ecosystem temperature is found to be very high and rainfall is very low. The nutrient cycling is poor due to scanty biota.

Biotic Components

(i) ***Producers.*** These are shrubs, especially bushes, some grasses, and a few trees. The shrubs have widespread-branched root system with their leaves, branches and stems variously modified. Sometimes a few succulents like cacti are also present. Some lower plants like lichens and xerophytic mosses may also be present.

(ii) ***Consumers.*** Insects, reptiles, nocturnal rodents, birds, camels, etc., are the main consumers.

(iii) ***Decomposers.*** These are very few, as due to poor vegetation the amount of dead organic matter is correspondingly less. These are some fungi and bacteria, most of them are thermophilic.

Aquatic Ecosystem

There are many kinds of aquatic ecosystems ranging from small temporary puddles to large ocean. They differ widely with regard to abiotic factors and living organisms. The important aquatic ecosystems are described below.

A. Pond or Lake Ecosystem

A pond or lake is a good example of a self-sufficient and self-regulating ecosystem (*Fig. 3.18*). Location size, depth and substratum of a pond or lake constitute the biology of the ecosystem. The various components of the ecosystem are as follows:

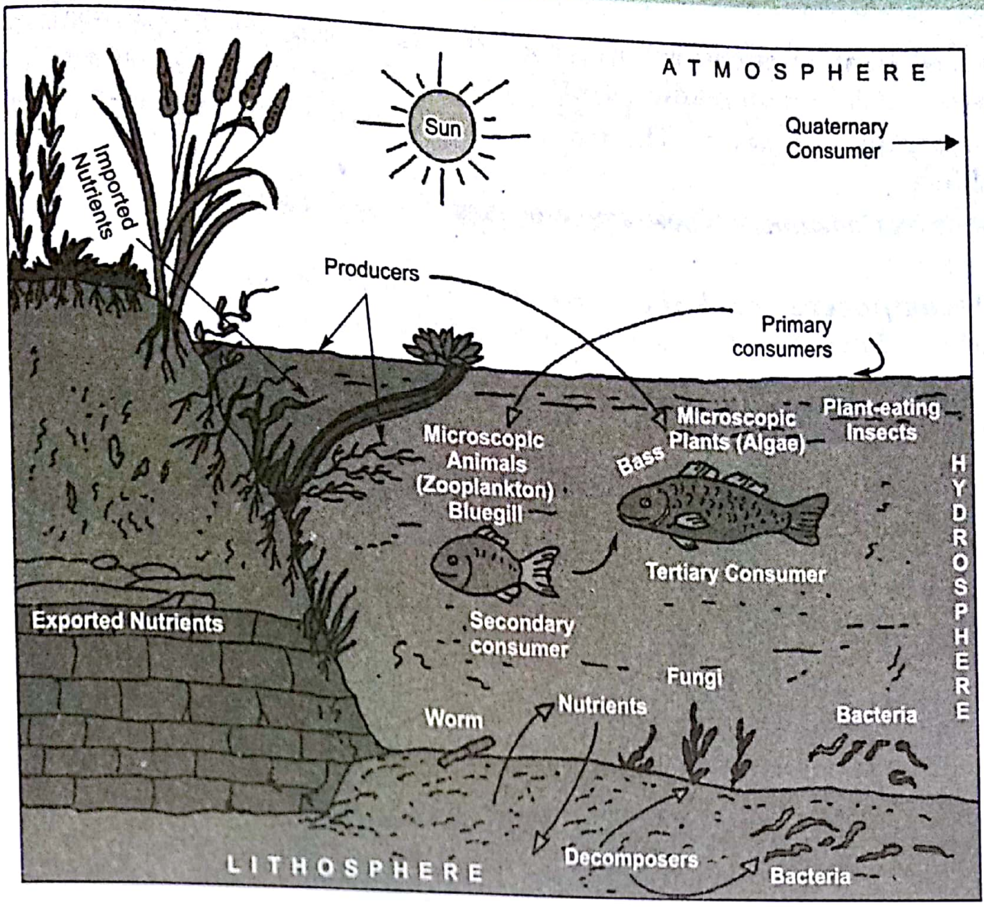

Fig. 3.18. Pond ecosystem.

Abiotic Components

Temperature, light, water, and several inorganic and organic substances like C, H, O, N, P, Ca, S, and carbohydrates, proteins and lipids make abiotic components. Some proportions of nutrients are in solution state but most of them are present stored in particulate matter as well as in living organisms. The amount of minerals present at any time in the physical environment of the pond is called **standing state.**

Biotic Components (Fig. 3.19)

(*i*) ***Producers.*** These include green photosynthetic organisms and are of two types: *Phytoplanktons and Macrophytes.*

(*a*) *Phytoplanktons.* These are minute floating or suspended lower plants belong to some algae and flagellates. *Ulothrix, Spirogyra*, *Oedogonium*, *Chlamydomonas*, *Zygnema*, *Volvox*, *Pandorina*, *Cosmarium*, *Scenedesmus*, *Closterium*, *Anabaena*, *Pediastrum*, *Microcystis*, diatoms, etc. are common algal phytoplanktons.

(*b*) *Macrophytes. Ceratophyllum*, *Hydrilla*, *Utricularia*, *Vallisneria*, *Jussiaea*, *Nitella*, *Wolfia*, *Lemna*, *Spirodella*, *Pistia*, *Eichhornia*, *Azolla*, *Salvinia*, *Trapa*, *Typha*, *Marsilea*, etc. are included in this category. This may be classified further into submerged, free floating and amphibious plants.

(*ii*) ***Consumers***

(*a*) *Primary Consumers.* These include zooplanktons and benthos forms. Zooplankton comprises ciliates, flagellates, other protozoans, small crustacean like Copepods and Daphnia, etc. These animals drift in the water current and are found along with phytoplankton upon which they feed. Benthos or bottom forms comprise the bottom dwelling animals, *e.g.*, annelids and molluscs, which feed on plants directly or on plant remains at the bottom.

(*b*) *Secondary Consumers.* These are the carnivores which feed on the herbivores, *e.g.*, insects and fish.

(*c*) *Tertiary Consumers.* These are some large fishes as game fish that feed on the smaller fishes.

(*iii*) ***Decomposers (or Microconsumers).*** Several bacteria, fungi (*Aspergillus*, *Cephalosporium*, *Phythium*, etc.) and actinomycetes represent the group.

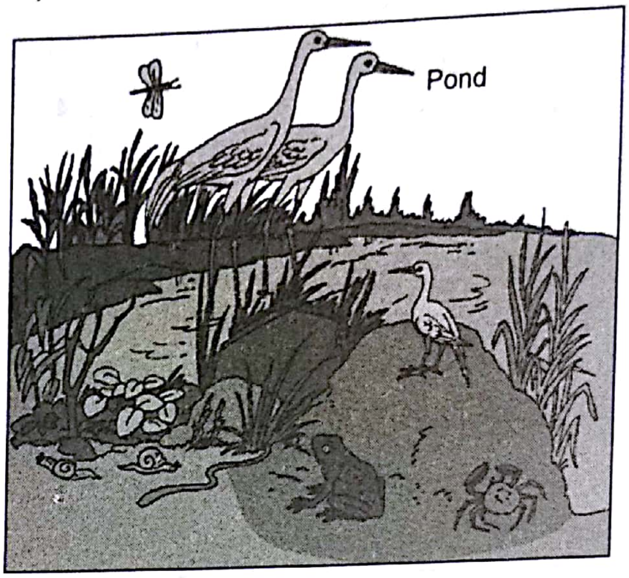

Fig. 3.19. Food chain in a pond.

B. River or Stream Ecosystem

The running water of a stream or a river is usually well oxygenated because it has a large surface area to absorb oxygen from the air. The various components of river or stream ecosystem are as follows.

Abiotic Components

The river or stream water has lesser mineral content and greater penetration of light. In the lower reaches water is usually muddy cutting down the light at the river bed.

Biotic Components

(*i*) ***Producers.*** In slow moving water of banks, phytoplanktons, attached algae, water grasses and other amphibious plants are the producers. In swift water floating populations of plankton are generally absent.

(*ii*) ***Consumers.*** These include flatworms, leeches, water insects, snails, fishes and crocodiles. Many birds and mammals also get their food from rivers and streams.

(*iii*) ***Decomposers.*** Several bacteria and fungi represent this group.

C. Ocean or Marine Ecosystem

Oceans cover more than two thirds of the earth's surface. The marine environment is characterised by its high concentration of salts and mineral ions. The ocean represents a very large and stable ecosystem. The main components of the ocean ecosystem are as follows.

Abiotic Components

Marine environment as compared with fresh water, appears to be more stable in chemical composition due to being saline. The other physio-chemical factors such as dissolved oxygen, light and temperature are also different waves of various kinds and tides prevail there. Ocean also show distinct horizontal and vertical zones (*Fig. 3.20*).

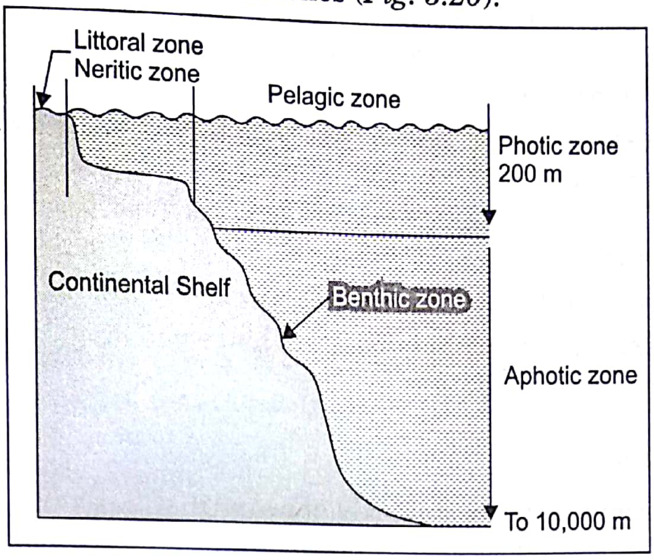

Fig. 3.20. Horizontal and vertical zonation in the sea.

Biotic Components (Fig. 3.21)

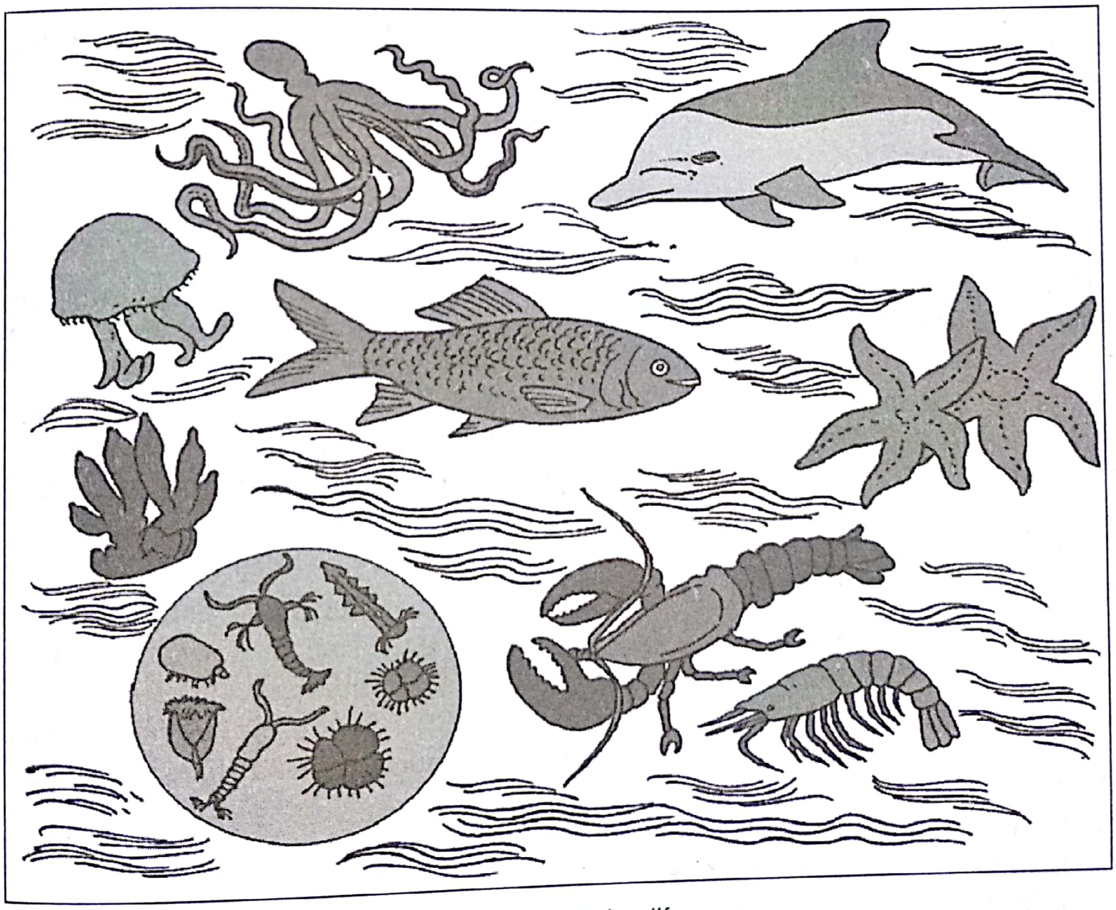

Fig. 3.21. Marine life.

(*i*) ***Producers.*** This category includes phytoplanktons and larger marine plants. The former group includes diatoms and dinoflagellates. The later group includes sea weeds (algae) belonging to chlorophyceae, phaeophyceae and rhodophyceae; and angiosperms. *Ruppia*, *Zostera*, *Posidonia*, *Halophila*, *Enhalus*, etc. are true marine angiosperms while various species of *Rhizophora*, *Avicennia*, *Sonneratia*, *Carapa*, *Aegiceros*, etc., represent the mangrove complex tidal woodlands.

(*ii*) ***Consumers.*** These are heterotrophic macroconsumers, being dependent for their nutrition on the primary producers. These are:

(*a*) *Primary Consumers.* The herbivores that feed directly on producers, are chiefly crustaceans, molluscs, fish etc.

(*b*) *Secondary Consumers.* Carnivorous fishes, such as Herring, Sahd, Mackerel, etc., are included in this group.

(*c*) *Tertiary Consumers.* Fishes like Cod, Haddock, etc., are the tertiary or top consumers.

(*iii*) ***Decomposers.*** They are chiefly bacteria and some fungi, which participate actively in decomposition of dead organic matter.

D. Estuarine Ecosystem

An estuary is a semiclosed coastal body of water that has a free connection with sea. It is strongly affected by tidal action, and within this sea water is mixed with fresh water from land drainage. River mouths, coastal bays, tidal marshes and bodies of water behind barrier beaches are some of the examples of estuarine ecosystems. Estuaries are generally productive because of water flow subsidies and abundant of nutrients. The chief biotic components of estuarine ecosystem are as follows:

Producers. These are macrophytes such as marsh grasses, seaweeds, sea grasses, benthic algae and phytoplankton.

Consumers. Oysters, crabs, several kinds of shrimp and many commerical sport fish represent this group.

Ecosystem Services

Healthy ecosystems are the base for a wide range of economic, environmental and aesthetic goods and services. The products of ecosystem processes are named as ecosystem services. For instance, healthy forest ecosystem purify air and water, mitigate droughts and floods, cycle nutrients, generate fertile soils, provide wildlife habitat, maintain biodiversity, pollinate crops, provide storage site for carbon and also provide aesthetic, cultural and spiritual values. Though value of such services is difficult to determine. It seems reasonable to think that these ecosystem services should carry a hefty price tag.

- **Purification of Air and Water.** Ecosystems and ecological processes play an important role in the break down and absorption of many pollutants created by humans and their activities. These include wastes such as sewage, garbage and oil spills. Several air pollutants and carbon dioxide produced by living organisms during respiration are absorbed and assimilated by the plants, thus purify the air. Some ecosystems especially wetlands and forests have qualities to breakdown and absorb pollutants, and act as water purifying systems.
- **Protection of Water Resources.** Plants and vegetation cover in water catchment help to maintain water cycles, regulating and stabilising water runoff, and acting as a buffer against extreme events such as flood and drought. Wetlands and forests

purify water, while mangroves at sea coast trap silts and reduce the impacts on marine ecosystems.

- **Soil Formation and Protection.** Biological diversity of ecosystem helps in the formation and maintenance of soil structure and the retention of moisture and nutrients. Biological diversity preserves the productive capacity of the soil, prevents soil erosion and land slides, safeguards coastlines and river banks and prevent degradation of the land. Tree and other vegetation add organic matter to the soil through litter formation.
- **Nutrient Cycling.** Ecosystems play a vital role in the recycling of the nutrients. The nutrients circulate among living and non living components of the ecosystem. Plants take up nutrients from the soil and air and convert them into a variety of biomolecules, forming the basis of food chains to be used by a wide range of other life forms. The soil nutrients are replenished through the process of microbial decomposition, and are made available to the plants.
- **Climate Regulation.** Vegetation play a vital role in climate regulation. There are evidence that suggest the undisturbed forests helps in rainfall by recycling water vapour at a steady rate back into the atmosphere. Vegetation has a moderating influence on local climates.
- **Maintenance of Biodiversity.** Ecosystems are the natural homes of diverse species of plants, animals and microorganisms. Ecosystems not only allow survival of biodiversity, but also maintain a balance between living things and the resources (such as food and shelter) they need to survive.
- **Other services.** Ecosystems provide sanctuary to breeding populations of birds and other predators which help to control insect pests in agricultural areas. Birds and insects roost in natural habitats that pollinate crops and other plants in surrounding areas. Maintaining healthy ecosystems improves the chances of recovery of plant and animal populations from unpredictable natural calamities such a fire, flood and cyclones and disasters caused by humans.

ECOLOGICAL SUCCESSION (CHANGES IN BIOTIC COMMUNITY)

The biotic communities are not stable but undergo regular changes in a definite manner with passage of time. Every community undergoes a series of changes until a group of organisms is established, which can live and reproduce most successfully in the area. *'The change of plant and animal communities in an orderly sequence in an area, resulting in establishment of stable or climax community is called ecological or biotic succession'*. A climax community does not evolve further because it is in perfect harmony with the environment of the area. The interaction among organisms in a community collectively termed biotic factors, influence the structure, composition and function of a community. The physical and chemical factors of an area determine immediately the kind of community that can be supported there. Bare rocks and shifting sand-dunes are unlikely support a forest community due to lack of nutrients and water.

The interacting organisms of the community slowly change the physical and chemical nature of the substratum as well as the factors of the environment. The process of change is called **reaction**. It includes weathering of rocky substratum, binding of soil particles, holding of water, decreasing the effect of wind and keeping the substratum moist and cool in summer or warm in winter. For example, the lichens growing on a rock produce acids that corrode the rock surface and help in holding fine particles of rock and sand. The decaying organisms, metabolic wastes and selective intake of chemicals change the composition of the substratum. As a result of reaction the habitat becomes less favourable to the existing biotic community and more favourable to some invaders. This builds a new biotic community. The latter sets in a new reaction and hence new invasions. Thus, continuous reaction and invasion bring about continuous change in the environment and structure of biotic community. Ultimately a biotic community is established, which is in perfect harmony with environment of the area. It remains permanent till disturbed.

The first community, which inhabit a bare area is called **pioneer community**. It has very little diversity and takes longest time to change the environment for invasion of the next community. The last and stable community in the area is called climax community. It is in perfect harmony with the physical environment. It is also termed as **climatic climax community**. It has maximum diversity and niche specialisation. The intermediate communities between pioneer and climax communities are called **seral** or **transitional communities**. The entire series of communities of biotic succession from pioneer to climax community is known as **sere**.

In any succession, each seral stage is a temporary community. It may remain for a very short period or it may continue for years together. Sometimes, some seral stages are by-passed or completely missed.

Successions beginning on watery habitats such as ponds, lakes, marshes etc. are called **hydrarch** and the whole sequence of developmental stages constitutes **hydrosere**. Successions beginning in dry habitats are termed **xerarch** and the different developmental stages of the succession are called **xerosere**. The xeroseres are of two types—(*i*) **Lithosere**—sequence of successional stages on a bare rock and (*ii*) **Psammosere**—sequence of successional stages on sand. The climax vegetation in any area is ultimately determined by its climate. The climax community throughout a climatic region is, therefore, the same whether it begins as a xerosere or a hydrosere. (*Fig. 3.22*)

Characteristics of Succession

Ecological succession is characterised by the following features:

1. It tends to progress from unstable biotic community to stable biotic community, *i.e.* complete adjustment with the environment.
2. Its several stages are so regular and directional that an ecologist can often predict the sequence of future communities.
3. In successive several stages there is tendency towards increase in species diversity, total biomass, niche specialization and humus content of the soil.
4. It tends to progress from simple food chains to complex food webs.
5. The habitat tends to modify from aquatic or dry conditions to mesic (moderately wet) conditions (*Fig. 3.22*).
6. Succession of plant and animal communities occurs side by side. However, plant succession is easily visible.

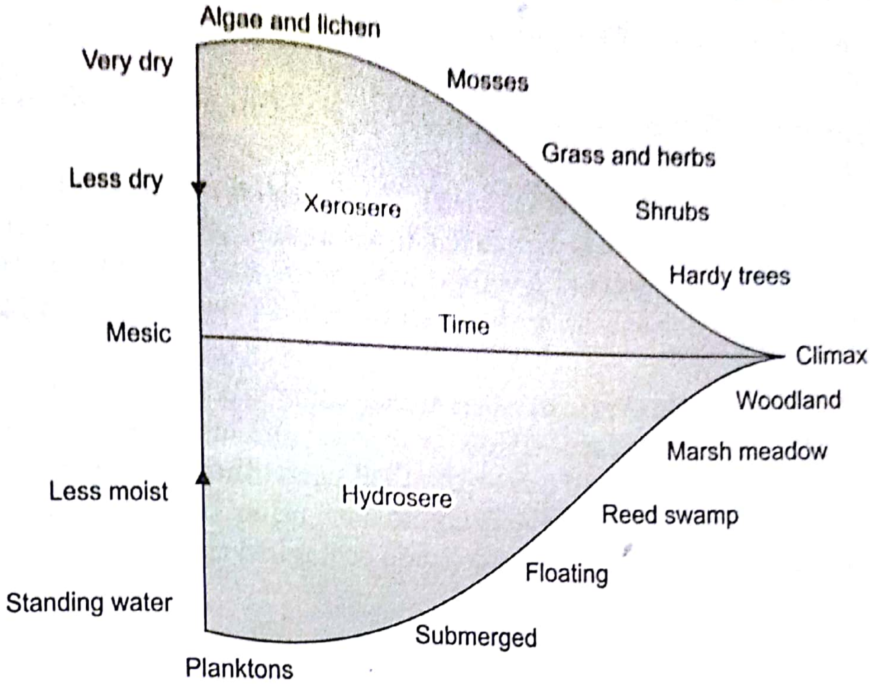

Fig. 3.22. Convergence in succession, xeric or aquatic to mesic vegetation.

Types of Succession

Depending upon the nudity of area, biotic succession is of two types—Primary and Secondary.

1. **Primary Succession.** The biotic succession that occurs on a substratum devoid of earlier life (*i.e.* bare rock, lava sediment, new island, newly formed pond or lake, etc.) is called **primary succession**. The sequence of successional stages of a primary succession is called **prisere.** Primary succession takes a very long time to reach the climax stage.

2. **Secondary Succession.** The biotic succession that occurs in an area which have become bare due to destruction of previously existing biotic community by fire, drought, land slide, earthquake etc., is called **secondary succession.** The sequence of successional stages of secondary succession is called **subsere.** Secondary succession takes comparatively much less time to reach the climax stage.

Mechanism of Succession

The whole process of primary succession is completed through a number of sequential steps, which follow one another. These steps in sequence are as follows:

1. **Nudation.** It is the development of a bare area which may develop due to several reasons, such as landslide, erosion, deposition of soil particles, clearing of forests, overgrazing or other catastrophic agency.

2. **Migration (Dispersal).** The seeds, spores or other propagules of the organisms reach the bare area. This process is called **migration**. It is generally brought about by air, water, animals and man. The first arrivals in a bare area are called **pioneers** or **pioneer colonisers.**

3. **Ecesis (Establishment).** The successful establishment of a species, after reaching to new area, as a result of adjustment with the conditions prevailing there, is known as **ecesis.** In plants, after migration, seeds or propagules germinate, seedling grow and adults start to reproduce. Only a few of them are capable of doing this under primitive harsh conditions and

Succession in a Pond or Lake (Hydrarch)

A hydrarch begins in a newly formed pond or lake. The water is deep in the middle and becomes progressively shallow towards the bank. The various seral stages (*Fig. 3.24*) of hydrarch are as follows.

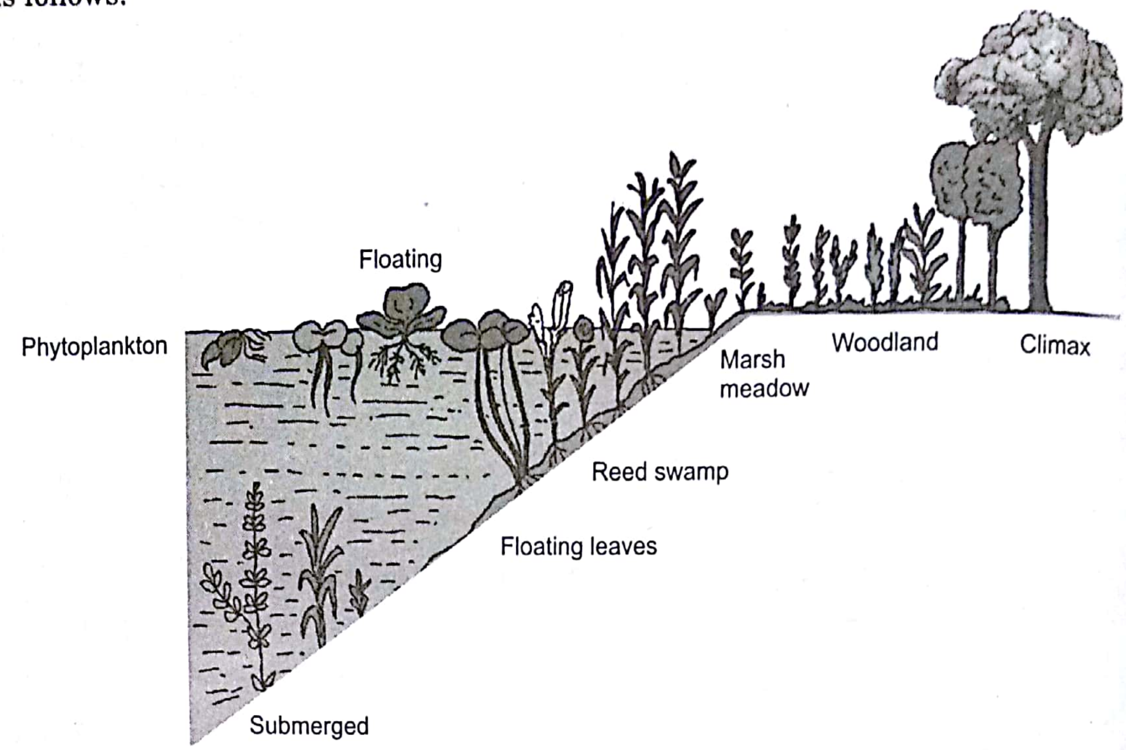

Fig. 3.24. Stages of plant succession in a lake or pond (Hydrosere).

1. **Plankton Stage.** It is the pioneer stage of a hydrosere. The spores of planktons reach to the newly formed water body through wind or animals. The planktonic stage mainly includes minute autotrophic organisms such as green flagellates, diatoms, cyanobacteria (blue green algae), unicellular, cololonial and filamentous green algae. These are called **phytoplanktons**. The population of phytoplanktons is balanced by **zooplanktons** that feed on the phytoplanktons. Death and decomposition of phytoplanktons mix with silt and form a soft mud at the bottom of pond, which favour the growth of next seral stage.

2. **Submerged Stage.** The soft mud mixed with organic matter favours the growth of submerged plants like *Potamogeton, Hydrilla, Vallisneria, Utricularia, Zenichellia* etc. They are rooted in the mud and fill the water. Accumulation of silt and sand around the plants make the water body shallower. Death and decay of sybmerged plants enrich the newly formed soil with humus. This makes the area less fit for the submerged plants and more suitable for next seral stage.

3. **Floating Stage.** The area is invaded by the species of floating leaved enchored plants like *Nymphea, Nelumbo,* etc. These plants make the water rich in mineral and organic matter. Some free floating species like *Azolla, Lemna, Wolffia, Pistia, Spirodela, Eichhornia* etc., also appear there. Rapid growth of floating stage further builds up the bottom and make the water shallower (0.3–1.0 m deep) on the periphery.

4. **Reed Swamp Stage.** The amphibious plants like *Typha, Phragmatis, Sagittaria, Scirpus* etc. replace the floating plants in the area. These plants produce abundant amount of organic matter and transpire huge amount of water. These plants build up shore by setting down sedimentary material and humus. The substratum now changes to a marshy soil.

5. **Sedge or Marsh Meadow Stage.** The marshy shore of the water body is invaded by *Carex* (sedge), *Cyperus, Juncus* etc. Some grasses like *Themeda, Dicanthium* and some herbs like *Caltha, Campanula, Polygonum* etc. also inhabit the area. The plants add more humus in the area.

6. **Woodland Stage.** The periphery of marsh meadow stage is invaded by some shrubby plants, which can tolerate bright sunlight as well as water logged conditions *e.g. Carnus* (bog wood), *Cephalanthus* (button brush) etc. They cast shade and make the soil dry by rapid transpiration. Some trees capable of tolerating sunlight and water logging such as *Populus* (cotton wood), *Alnus* (Alder) etc., also invade the area. These plants further lower down the water-table by their transpiration and build up more soil. Some shade enduring herbs grow under them.

7. **Climax Forest.** Many trees, which have shade loving seedlings invade the area. They grow to greater height. The previous occupants disappear and give place to more shade tolerant and mesophytic species. Thus, the area once under deep water becomes finally transformed into a forest. It should be remembered that the nature of the climax community will depend upon the climate. A forest community will develop only if the climate is moist. In dry climate the climax community may be a grassland or some other xeric community.

Changes in Community Characteristics and Climax

The exact sequence of species and communities that appear during primary or secondary succession varies with the habitat conditions. The seral stages from pioneer to climax stages differ both in structure and functions. The trends in various changes during succession are listed in *Table 3.2*. Generally, the average size of individuals increases and the community organisation becomes more complex in the climax community as compared to seral community. The efficiency of energy use and nutrient conservation increase as the community progresses towards the climax stage. The food web become more complex in the climax stage.

Table 3.2. *Trends of Changes in the Ecosystem's Characteristics During Succession*

Ecosystem Attribute / Characteristics	*Seral Stages*	*Climax Stage*
Community Structure		
(*i*) Size of individuals	Small	Large
(*ii*) Ecological niches	Few, generalised	Many, specialised
(*iii*) Community organisation	Simple	Complex
Community Functions		
(*i*) Food chains and food web	Simple	Complex
(*ii*) Efficiency of energy use	Low	High
(*iii*) Nutrient conservation	Low	High

The climax community is more or less stable with the climate. The species composition at the climax stage is determined by the climate of the region and local conditions of soil, topography and water availability. The climax stage reflects the highest level of vegetation and the associated fauna that can be supported under the given environmental conditions.

Importance of Succession

The ecological succession is of great practical importance in many activities of man in the following manner:

1. It provides information, which helps to have a controlled growth of one or more species in a forest by preventing the invasion of other species in the area.

2. Pastures can be maintained by not allowing biotic succession to proceed further through grazing or fire.

3. It also helps in reforestation and forest management programmes.

IMPORTANT TERMS

1. **Agroecosystem.** Anthropogenic or man-made ecosystem basically agricultural fields.
2. **Biogeochemicals (Biogenetic Nutrients).** The elements provided by the earth to the living organisms.
3. **Biogeochemical Cycle.** Movement or circulation of biogenetic nutrients through the living and non-living components of the biosphere or any ecosystem.
4. **Biomes.** Major ecosystems with their groups of climax plants and associated animals.
5. **Biotic community.** A group of populations of different species inhabiting in a common environment and interacting with one another.
6. **Biotic Succession.** The change in biotic communities in an orderly sequence in an area resulting in establishment of stable or climax community.
7. **Competition.** Interaction between two species which suffers adverse effects.
8. **Detritivores.** Detritus feeding invertebrates which breakdown detritus into small pieces.
9. **Detritus.** Dead plant parts and animal remains.
10. **Ecosystem.** A segment of nature consisting of communities of living beings and physical environment, which interact and exchange materials between them.
11. **Food Chain.** The transfer of energy from one trophic level to the next through a series of organisms with repeated eating and being eaten.
12. **Food Web.** A network of food chains, which are interconnected at various trophic levels, so as to form a number of feeding connections amongst different organisms of an ecosystem.
13. **Macrophytes.** Rooted plants found in shallow waters.
14. **Population.** Group of individuals of the same species inhabiting the same area.
15. **Productivity.** The rate of biomass or organic matter production by the organisms.
16. **Succession.** Successive replacement of communities in an area over a period of time.
17. **Stratification.** Formation of different layers or strata of different species in a community.

TEST QUESTIONS

Multiple Choice Type Questions

Select the correct option to the following questions

1. An ecosystem consists of

   (*a*) Green plants and animals
   (*b*) Green plants and decomposers
   (*c*) Producers and consumers
   (*d*) Green plants, animals, decomposers and abiotic environment.

4 Bio-geo-Chemical Cycles

INTRODUCTION

The earth is the source of matter in the living organisms. Out of over one hundred elements about less than two dozen are used by the organism in forming the living matter. They are called **essential elements.** As these elements are provided by the earth and are used by the organisms for their body building and metabolism, they are called **biogenetic nutrients** or **bio-geo-chemicals**. The elements forming the bodies of the living organisms are derived from the upper portion of the lithosphere (mainly soil), the hydrosphere and the atmosphere. The total amount of living material contained in all the organisms that have ever existed on the earth, for exceeds the total mass of the earth. This is because the materials have been used again and again in the formation of new generations of the organisms. In other words the matter is continuously recycled. *The movement or circulation of biogenetic nutrients through the living and non-living components of the biosphere or of any ecosystem is called cycles of matter or bio-geo-chemical cycling* (*Fig. 4.1*).

In biosphere the biogenetic nutrients exist in two states—reservoir pool and cycling pool.

(*i*) **Reservoir pool** is the pool of nutrients from which the nutrients are slowly transferred to cycling pool.

(*ii*) **Cycling pool** is the pool of nutrients, which is repeatedly exchanged between the biotic and abiotic components of the biosphere.

TYPES OF BIO-GEO-CHEMICAL CYCLES

There are two types of bio-geo-chemical cycles—gaseous and sedimentary.

Gaseous Cycles

In these cycles, the reservoir pool is the atmosphere or ocean. The biogenetic materials [illegible] pass through a gaseous phase before completing the cycle. Carbon (as carbon dioxide), oxygen, nitrogen and water (as vapour) have gaseous cycles. The gaseous [illegible] take less time to complete.

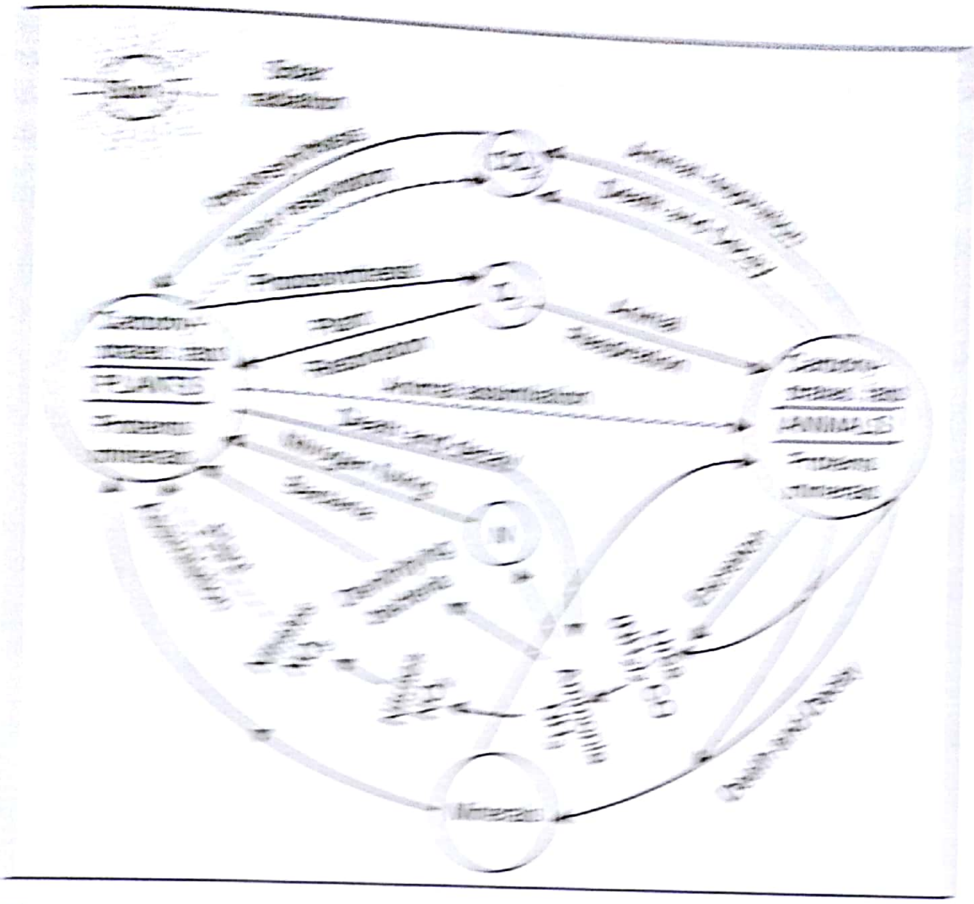

Fig. 4.1. Bio-geo-chemical cycles. (Carbon dioxide, oxygen, nitrogen and many minerals pass cyclically between the living (plants, animals, microbes) and nonliving (atmosphere, soil, water) components of the system. [illegible])

Sedimentary Cycles

In these cycles the reservoir pool is lithosphere. The biogenetic materials involved in circulation are non-gaseous. Elements such as phosphorus, calcium and sulphur have sedimentary cycles. The sedimentary cycles are usually very slow as the elements may get locked up in rocks and go out of circulation for long periods. The major cycles of matter, which are important to life are discussed below.

CARBON CYCLE (Fig. 4.2)

Carbon is a component of all organic compound of the organisms. These include carbohydrates, lipids, nucleic acid, enzymes, hormones etc. It is present in the abiotic environment as:

(*i*) Carbon dioxide of the air.

(*ii*) Dissolved carbon dioxide or carbonic acid and bicarbonates in water or hydrosphere.

(*iii*) The carbonates and graphite present in the rocks in the earth's crust.

(*iv*) The carbon present in the fossil fuels such as petroleum and coal.

The major source of carbon for the living world is carbon dioxide. The atmosphere contains about 0.03 per cent carbon dioxide. The major process that brings carbon from the environment into the living world is photosynthesis. During photosynthesis, the green plants, called producers pick up carbon dioxide from the atmosphere and change the same into organic compounds. It is estimated that the amount of carbon fixed by photosynthesis is nearly 7×10^{13} kg per year. Oxygen is produced as a by-product. It is estimated that one hectare of a healthy forest absorbs about 30 tonnes of carbon dioxide and produces about 10 tonnes of oxygen annually.

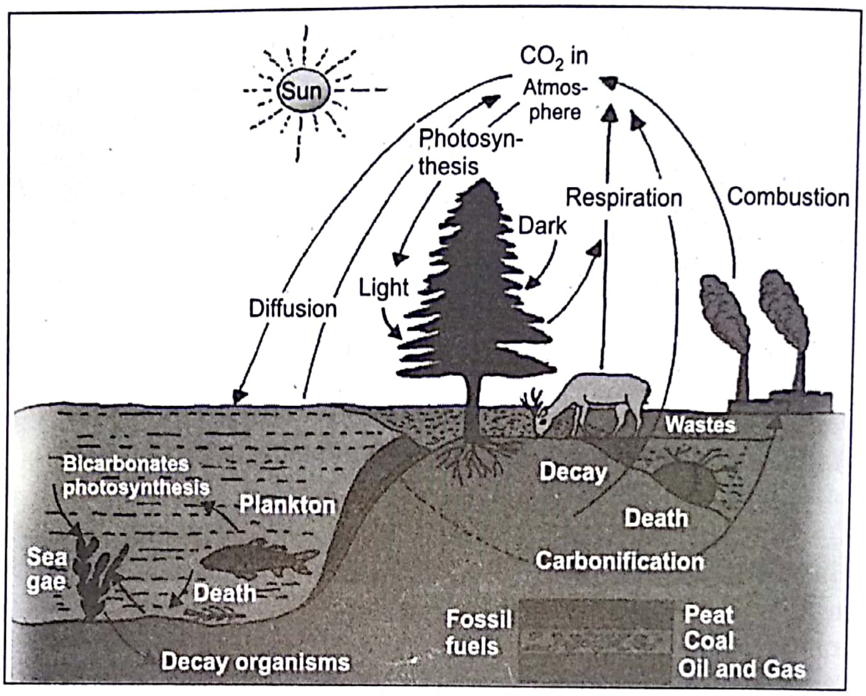

Fig. 4.2. The carbon-cycle.

Carbon fixed by the producers enters the food-chain and is passed to herbivores, carnivores and decomposers. The carbon content of the abiotic environment, reduced by photosynthesis, is replenished through following processes:

(*i*) respiration of living organisms,

(*ii*) decomposition of organic matter and dead bodies of the organisms by decomposers,

(*iii*) burning of wood and fossils,

(*iv*) weathering of carbonate rocks and

(*v*) volcanic erruptions.

A large number of organisms burried deep into the layers of the earth due to major earthquake or otherwise, gradually transform into coal, petroleum and natural gas under pressure of high temperature. This process takes millions of years. The carbon remains locked up in coal and petroleum till man uses them and puts it back in circulation. Some carbon also remains out of cycle when it gets incorporated in hard shells and skeletons of animals. Thus, natural exchange between lithosphere and hydrosphere or atmosphere is a very slow process.

The major exchange in carbon cycle is between organisms and the atmosphere or hydrosphere. This cycling is a self regulated feed-back system. But recently, it has been upset by man's activities such as large scale deforestation and excessive burning of fossil fuels. As a result carbon dioxide content of the atmosphere is increasing. It may disturb the climatic conditions of the world and melt away polar as well as alpine ice.

NITROGEN CYCLE (*Fig. 4.3*)

Nitrogen is a component of amino acids, proteins, nucleotides and nucleic acids, which are essential structural and functional components of living organisms. Nitrogen is picked up

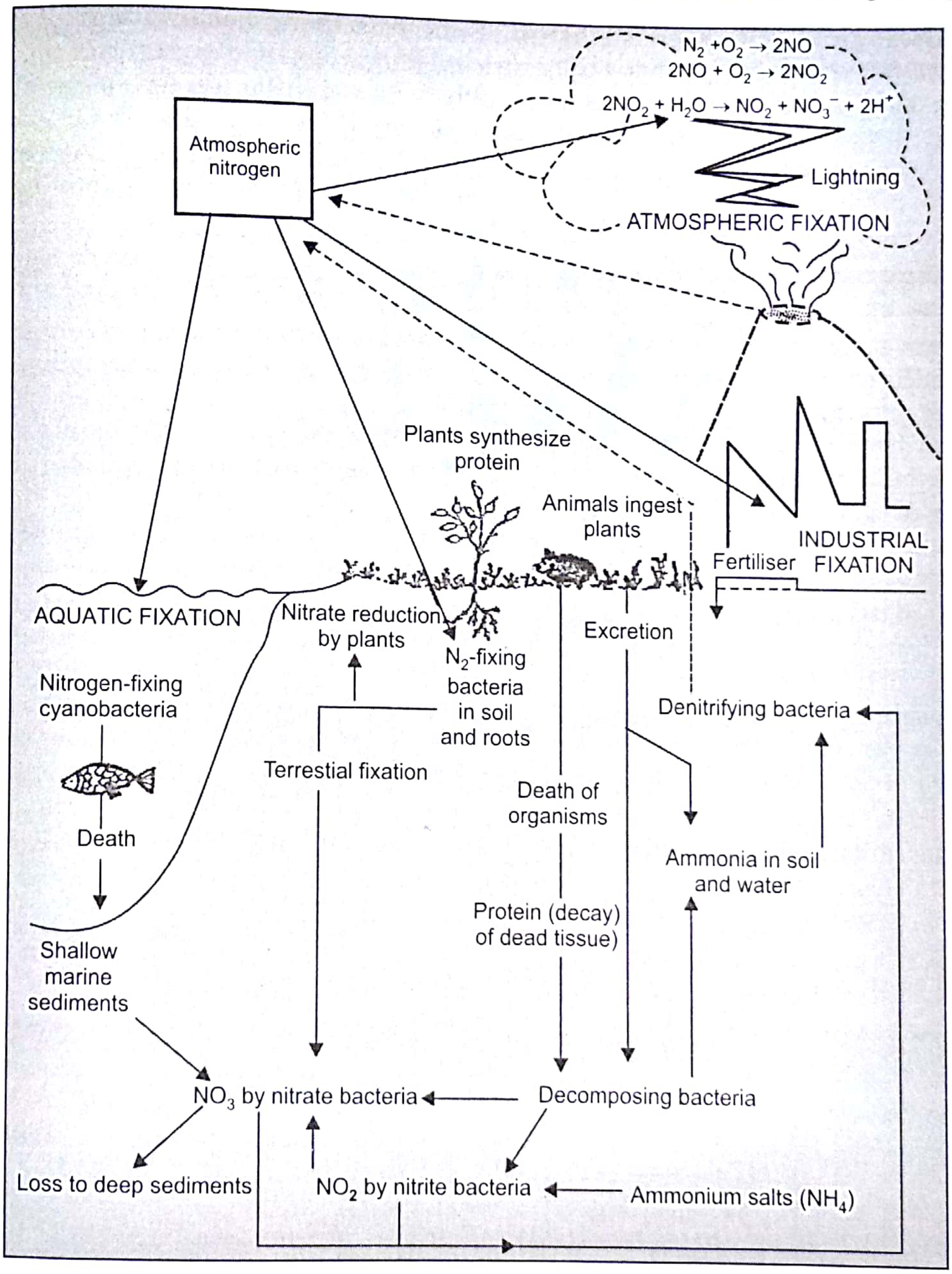

Fig. 4.3. The nitrogen cycle.

as inorganic compounds and is changed into organic form by plants and some prokaryctes. Plants and prokaryotes pick up inorganic nitrogen either as nitrates or ammonium ions.

Atmosphere is the major source of nitrogen, as four fifth (*i.e.*, about 79%) of the air is made up of nitrogen. This nitrogen is in the elemental or molecular state which cannot be used by plants. It has to be fixed or combined with other elements such as hydrogen, carbon or oxygen, before it can be utilized. This process is called **nitrogen fixation.** Nitrogen fixation is of three types—atmospheric, biological and industrial.

1. **Atmospheric Nitrogen Fixation.** Nitrogen of the atmosphere combines with oxygen in photochemical and electrochemical reactions to form oxides of nitrogen. They get dissolved in water and combine with other salts to produce nitrates. The nitrogen fixed in this manner is only 35 mg per square metre per year.

2. **Biological Nitrogen Fixation.** Some free living bacteria (*e.g., Azatobactor, Clostridium, Beijerinckia*), Symbiotic bacteria (*e.g., Rhizobium*) and certain cyanobacisria (*e.g., Anabaena, Nostoc, Aulosira, Tolypothrix*) are able to fix molecular nitrogen of the atmosphere in the form of ammonia. It is called **biological nitrogen fixation**. It adds 140—700 mg per square metre per year of nitrogen in the soil. The total amount of nitrogen fixed by nitrogen fixing micro-organisms is 175 million tonnes or about 70 per cent of our total supply. The remaining amount comes form chemical fertilizer factories.

3. **Industrial Nitrogen Fixation.** Ammonia is produced in industry by combining nitrogen and hydrogen under pressure and high temperature (Haber's process).

Plants absorb nitrogen from the soil in the form of nitrate or ammonium ions. These ions are utilized to form amino acids, which are later converted into proteins and other nitrogenous compounds. A part of the plant proteins is consumed by the animals and is converted into animal proteins. The remaining is decomposed after the death of the plants. It releases nitrogen to the surroundings. In the animal body the proteins are broken down into nitrogenous wastes like urea, uric acid and ammonia. These nitrogenous wastes are excreted out the dead bodies of animals and animal wastes are acted upon by decomposing microorganisms such as *Actinomycetes* and fungi to convert various nitrogenous compounds into ammonia.

Most of the ammonia produced in the soil is acted upon by nitrifying bacteria to produce nitrogen. First, the ammonia is converted into nitrogen by *Nitrosomonas* and *Nitrococcus*. The nitrites are then converted into nitrates by *Nitrobactor* and *Nitrocystis*. The nitrate become available to plants for absorption. Some nitrate and ammonium salts are added to the soil as fertilizers. A part of nitrate is lost through leaching and precipitation. It becomes constituent or rocks and become available very slowly either through volcanic erruptions or erosion of the rocks.

Under anaerobic conditions such as water logged soils denitrifying bacteria (*e.g. Pseudomonas aeruginosa* and *Thiobacillus denitrificans*) use nitrites and nitrates of the soil as source of oxygen and convert the same into molecular nitrogen.

The various types of microorganisms involved in nitrogen cycle are given in *Table 4.1.*

Table 4.1. ***Organisms Involved in Nitrogen Cycle***

Activity	*Organisms involved*	*Role*
1. Nitrogen Fixation	(*i*) *Rhizobium* (a symbiotic bacterium)	Conversion of atmosphere nitrogen into nitrogen compounds
	(*ii*) *Azatobacter*	"
	(*iii*) Cyanobacteria (Blue green alage)	"

2. Ammonification	(*i*) Putrifying bacteria	Conversion of complex nitrogenous components of dead bodies into ammonia
	(*ii*) Fungi	"
3. Nitrification	(*i*) *Nitrosomonas* (a bacterium) *Nitrococcus* (a bacterium)	Conversion of ammonia into nitrites
	(*ii*) *Nitrobacter* (a bacterium) *Nitrocystis* (a bacterium)	Conversion of ammonia into nitrites
4. Denitrification	*Pseudomonas* (a bacterium)	Conversion of nitrates to free nitrogen

OXYGEN CYCLE (*Fig. 4.4*)

Oxygen is another essential element for living organisms. It is required for life processes such as respiration. The reservoir of oxygen is atmosphere, where it occurs to the extent of 21 per cent of the air. Oxygen also occurs in combined state as carbon dioxide and water.

Atmospheric oxygen enters the living organisms in the process of respiration and oxidises organic food into carbon dioxide and water. Thus, during respiration oxygen enters the living world in free state and is released in combined state. Oxygen also enters the plants as carbon dioxide and water during photosynthesis. In this process molecular oxygen is released into the environment for reuse in respiration. The concentration of oxygen in the air and water are maintained by equal rates of its use in respiration and release in photosynthesis. Oxygen is also released as a part of carbon dioxide by decay of dead organic matter.

Oxygen also plays a significant role in protecting the earth from ultraviolet rays entering from the space. The molecular oxygen (O_2) combines with atomic oxygen (O) to produce ozone (O_3) layer in the outer atmosphere. The ozone layer screens off most of the ultraviolet rays entering to the atmosphere from outer space.

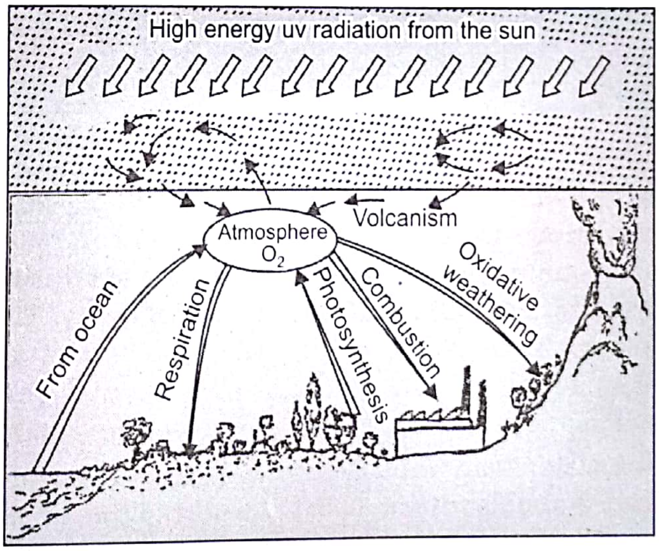

Fig. 4.4. The oxygen cycle.

WATER CYCLE OR HYDROLOGICAL CYCLE (*Fig. 4.5*)

Water is indispensable for life. About 60–90% of the body weight of an organism is made of water. Water is required for solubilization of chemicals and several biochemical reactions. There is a constant exchange of water between the air, land and sea, and between the living organisms and their environment. Thus, there are two overlapping water cycles in nature—the larger **global water cycle**, which does not involve the living organisms and the smaller **biological water cycle**, that involves living systems:

1. **Global Water Cycle.** Water evaporates from oceans, seas, rivers and lakes, which are part of hydrosphere. The water vapour gets condensed and leads to the precipitation in the form of rain, snow and hailstorm, which falls on the soil or returns directly into water bodies. Most of the rain water on soil percolate deep to become a part of water table and seep into the oceans. The surface rain water and the water formed by the melting of ice and snow flow to the rivers and streams and finally join the sea. It has been estimated that the total amount of precipitation of water on earth is about 4.6×10^{20} g per year, while that the water suspended as water vapour is only 0.13×10^{20} g. This means that the atmosphere must be refilled with water vapour 34 times in a year.

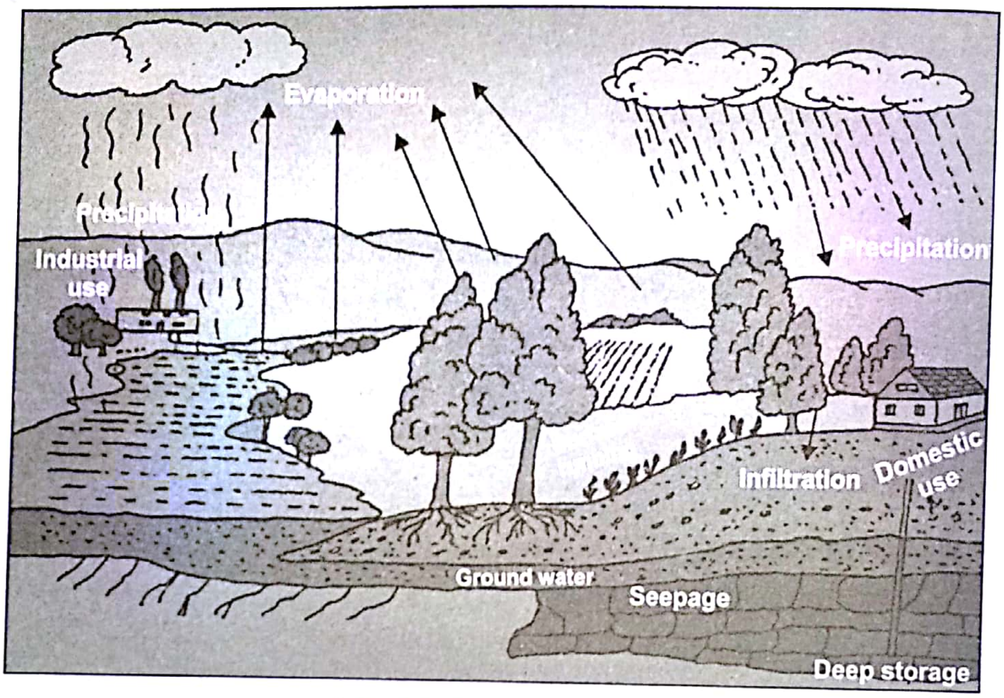

Fig. 4.5. The water cycle.

2. **Biological Water Cycle.** The small or biological water cycle involves entry of water into living-beings and its return to the physical environment. Aquatic plants and animals obtain water from their surroundings. Some water is excreted out during their life time. While the remaining is returned after death through the process of decay. Terrestrial plants absorb water from the soil through their roots. Major part of it is lost through transpiration. Transpiration keeps the surrounding air cool during summer and warmer during winter. It, thus, determines the microclimate of the area. It also causes dew and local rain.

Land animals drink water from water bodies. Part of their water supply also met by the water present in their food. Animals return a part of water to the air as vapour by respiration or to the soil by excretion. Water is also added to the environment by death and decay of the terrestrial organisms. Water vapour formed by transpiration and respiration form clouds and enters to the global water cycle.

PHOSPHORUS CYCLE (*Fig. 4.6*)

Phosphorus is an important element for all living organisms. It is a constituent of nucleic acids, phospholipids, ATP, bones and teeth. It takes part is metabolic reactions involved in release of energy from food and utilization of this energy in various functions of the body.

There is no atmospheric phase in phosphorus cycle. Therefore, phosphorus show sedimentary type of cycle. Phosphorus is mostly used as phosphates. Crystalline rocks are the major natural source of phosphates for the living organisms. The rocks undergo slow process of weathering and release phosphates in the soil. Phosphates are also added to the soil by man in the form of artificial fertilizers. A considerable amount of phosphorus from the soil is washed into the sea by rains and floods. Seaweeds take up phosphorus from sea water and passes it to fishes and sea birds. The sea birds deposit their phosphorus rich faeces called **guano** on land. Plants absorb phosphorus as phosphate ions from the soil. Animals obtain phosphates by eating plants as food. When organisms excrete or their bodies decompose, phosphorus return to the surroundings.

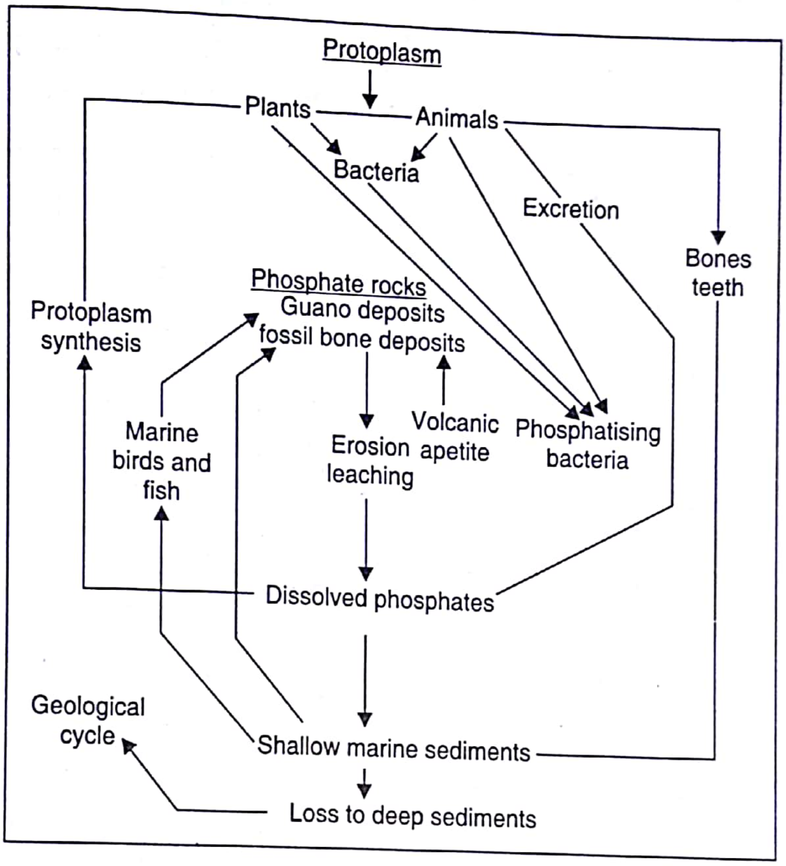

Fig. 4.6. The Phosphorus Cycle

When phosphates from compounds with metals like aluminium, iron or calcium phosphorus become unavailable to the plants and is lost to the cycle until chemically changed. Phosphorus incorporated in bones and teeth also remain outside the natural cycle for a long time as the bones and teeth are resistant to decay.

SULPHUR CYCLE (*Fig. 4.7*)

Sulphur is a structural constituent of certain protein, vitamins and enzymes. Sulphur occurs in elemental form and also as sulphides and sulphates in soil, water and rocks. Plants absorb sulphates from soil and water, and incorporate sulphur in proteins and certain other biomolecules. Animals get sulphur from plants as food. Some animals get sulphur from water also. During decomposition of plants and animal bodies the organic sulphur is mineralised as sulphates by bacteria and fungi under aerobic conditions. However, under anaerobic conditions, such as in marshes, some bacteria change organic sulphur to sulphides. Sulphides are harmful to most organisms. But sulphur bacteria oxidise them to sulphate and bring back the element to the cycle.

There is also a small gaseous phase. Hydrogen sulphide is released into atmosphere from lakes, marshes or water logged soils. In atmosphere it is oxidised into sulphur dioxide. Sulphur dioxide is also released into air through combustion of fossil fuels and smelting. Sulphur dioxide gets dissolved in rain water and brought back to the earth. A large part of sulphur is washed away by rain water and carried to the sea, where it may get locked up in sedimentary rocks. From the sea, sulphur gets back to land through food-chains, sea sprays and geological upheavals.

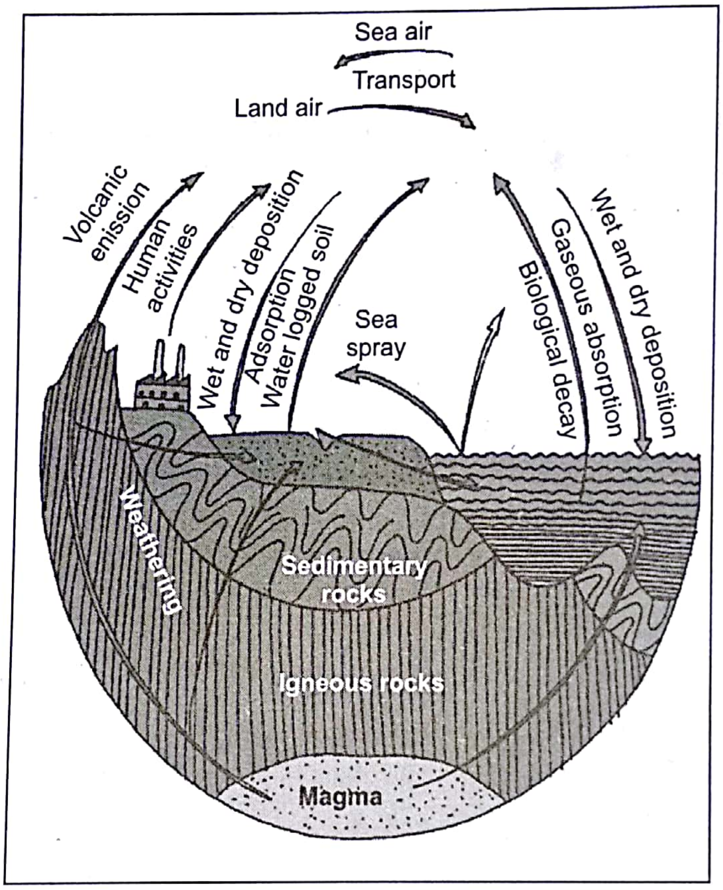

Fig. 4.7. The sulphur cycle.

OTHER MINERALS

Some other minerals such as calcium, magnesium, manganese, iron etc. are also cycled in nature. Most of them occur in rocks, from where they are released slowly by water and wind action. These are either blown into the air as dust or absorbed by plants through their roots. Recycling occurs between the organisms and their surroundings. Some organisms such as molluscs and cords deposit a substantial quantity of calcium in their shells and skeleton and are not available for quick cycling.

Bio-geo-chemical cycles occur on a grand scale and magnitude. All sedimentary elements return very slowly to the cycle via the sea food-chains or through coastal sea water sprays. This process may take hundreds to millions of years.