2. **Paleoecology.** It is concerned with the organisms and geological environments of the past.

3. **Cytoecology.** It deals with the cytological details of the species on populations in relation to different environmental conditions.

4. **Ecosystem ecology.** It deals with the structure and working of ecological systems in relation to space and time and also with the analysis of components of ecosystem, In this, special emphasis is laid on the reciprocal relationship between living and non-living systems.

5. **Conservation ecology or Resource ecology.** It is concerned with the proper management of plant, animal, soil, water and mineral resources for human welfare.

6. **Ecological energetics and Production ecology.** These modern branches of ecology are still in developing stage. These deal with the mechanisms and quantity of energy conversion and flow of energy through organisms. Energy production processes, rate of increase in organic weights of organisms in relation to space and time are also discussed in this branch of ecology.

Plant Ecology and other branches of Science

Ecology is a synthetic branch of biological science which draws source materials from many other sciences. It is fundamentally related to morphology, taxonomy, physiology, biochemistry, cytology, genetics etc. Various other sciences, such as physics, mathematics, statistics are also being increasingly used in the study of ecological problems. Application of radioactive isotopes, use of many modern and advanced instruments like spectrometer, infrared gas analyser, flame photometer, computers in the analysis of data, calorimeters, phytotrons for culturing the plants in environment controlled chambers and many other equipments are common in ecological researches. Besides botany, zoology, chemistry and physics, the knowledge of climatology, geography, pedology and geology is also essential in the study of complicated problems of plant ecology.

Application of plant ecology

The study of plants in their environment has yielded a large body of knowledge which provides aids to the science of conservation of natural resources. The knowledge of ecology is of great help in controlling soil erosion, reforestation, restoration of wild animals as well as grassland vegetation and flood control. Plant ecology is directly related to silvics and silviculture and other branches of forest biology. In *British Commonwealth Forestry Terminology* (1953) **silvics** has been defined as the study of general characteristics and life history of forest trees and crops with particular reference to environmental factors as the basis for practice of silviculture while the **silviculture** has been defined as the art and science of culturing forest trees and crops.

Every farmer or gardener is ecologist, since by such practices as cultivation, irrigation, artificial pollination and spraying, he affects the plant behaviour.

Knowledge of ecology is being applied in agriculture, food production and horticulture. The soil conservation practices are in use these days in agronomy. The modern ecology revolves round the biological production processes and ecological energetics. The International Biological Programme (IBP) was launched since July 1, 1967 to study the biological basis of organic productivity and conservation of natural resources in relation to human welfare. Launching of this programme has given impetus to the ecologists all over the world and over 70 nations including India have participated in the IBP studies at either national or international level. The future of ecology and indeed of biology is likely to be changed by some international programmes such as 'Man and Biosphere' (MAB).

The history of ecology in India is not very different from that of any other country in the world. Indeed, it has been much influenced by western school which provided the leadership. Publications of botanical explorations by Dudgeon (1920), Saxton (1922), Bor (1942), Osmaston (1926) and Champion (1936) provided enough opportunity for ecological investigation in India. Professor F.R. Bharucha, a student of Braun-Blanquet, established the first school of ecology at Bombay. This school contributed a great deal of informations on the biological spectra of different regions of India and on the phytosociology of grass and forest vegetation. The second school of ecology developed under the leadership of Professor R. Mishra first in Sagar and later at Varanasi. At present, many secondary schools of ecology are emerging at Ujjain, Ahmedabad, Pilani, Jodhpur, Pondicherry, etc. and ecologists in these centres are engaged in different fields of study.

QUESTIONS

1. What is ecology? How is it related with other branches of biology?
2. What are different branches of ecology? Why study of ecology is important for man?

2

THE ENVIRONMENT

The life containing and life supporting environment of the world is restricted to a very irregular layer (5 to 20 km thick) around the globe. This thin veil of living material on the earth is called *ecosphere or biosphere.* Thus, the biosphere is that part of earth in which life exists (Hutchinson, 1970). Biosphere may be divided into *parabiosphere* and *eubiosphere.* The parabiosphere is that part of biosphere where environmental conditions are not entirely hospitable and this includes such broad areas as higher altitude, the polar regions, the deepest ocean troughs, the most extreme deserts and certain localised regions as volcanoes, geysers and heavily polluted areas of land and water. The remaining portion (the *eubiosphere*) is composed of three chief media—air, water and earth or land and accordingly it has been divided into three subdivisions :

(*i*) Atmosphere
(*ii*) Hydrosphere
(*iii*) Lithosphere or pedosphere

In ecology we study the reciprocal relationship between an organism or a group of organisms and its environment. The environment literally means the surrounding. The environment is the aggregate of all those things and set of conditions which directly or indirectly influence not only the development or growth and quality of life of individual organisms but also the communities at a particular place. It is comprised of a number of factors which interact with one another and also influence the responses of the organisms. Any external force, substance or condition affecting the organisms in any way is referred to as environmental factor. Soil, moisture, wind and temperature are, thus, factors and the environment, thus is sum total of all such factors. The natural place where organisms or communities of organisms live is called *habitat.* The habitat implies a particular set of environmental factors in a given locality and is, therefore, generally used in a more concrete sense than the environment, as for example, water is the habitat of aquatic organisms and land is a habitat for numerous terrestrial organisms. Aquatic habitat comprises three major categories namely, *fresh water habitat, marine habitat and brackish habitat.* Biosphere can be divided into many major categories of land masses called *biomes.* Biomes are distinct large areas of earth with relatively homogenous climate and flora and fauna, as for example, deserts, forests, prairies etc. Biomes are subdivided into small units, each with its own particular set of physical conditions. These small units are called Zones. For example, a *forest biome* can be divided into *ground zone* and *canopy zone* and *desert biome* can be divided into *surface* and *subterranean zones*. The ocean can be regarded as single biome (the *marine biome*) which can be divided into *surface, abyssal* and *intertidal* or *littoral zones.*

Within each biome there may be numerous habitats, each characterised by a particular set of conditions and well adapted community of organisms. Within a particular habitat an individual is generally confined to restricted situation which is called *ecological niche.*

The environmental or the habitat factors influence the characters and composition of individual plants and plant communities. Any feature of an organism or its part which enables the organism to exist under conditions of its habitat is called an *adaptation*. An organism accumulates many adaptive features in it. Such features may ensure a degree of success either by allowing the plant to make full use of the amounts of nutrient, water, heat and light available to it or by providing a significant amount of protection against some unfavourable or adverse factors, such as very high or very low temperature, drought, parasitism and so on. The adaptive features of organism may be hereditary (*i.e.*, they may be genetically controlled) or they may be induced by the habitat factors.

In an ecosystem the species and its environment are taken as a complex *"whole"*. Environment, as pointed out earlier, in itself is a complex of factors acting, reacting and interacting with the organism complex. Thus, the organisms and their environment are wedded together and are in state of constant flux. Relationship between organisms and their environment are based on certain principles which are summarised as follows :

1. Everything influencing the life processes of an organism constitutes its environment.

2. Environment in a habitat may be considered into biotic and abiotic components and the activities of the organisms are influenced by the combined effects of various environmental factors.

3. An organism is a component of the environment and the materials and energy required for the maintenance of the body and sustenance of life of organisms constitute the abiotic environment.

4. An organism cannot exist in vacuum.

5. Life is the energy exchange process between the organism and environment and death means cessation of the exchange process.

6. The environment requirements of different organisms differ from individual to individual and also with age and need.

7. Life activities are influenced by that environmental component which occurs in minimum quantity (Liebig's law of limiting factor).

8. Life activities of an organism are influenced by the minimum or maximum quantity of the environmental components or factors, as for example, nutrients, light, temperature, moisture. Based on this principle Shelford founded the ***law of tolerance***.

9. Tolerance limits of an individual for different environmental factors may be different.

10. An organism may show different tolerance limit for a particular environmental factor in different habitats and at different age and stage of life history.

11. Organisms having wide tolerance limits for many environmental factors are widely distributed.

12. An organism is a product of nature (genetic set-up) and nurture (environmental upbringing). The inherited qualities are unfolded in proper environment.

13. Organisms react with the external stimuli caused by the environmental changes. The reactions may be exhibited by movements (migration) or adaptational changes in the body or physiological activities. All such adaptations have survival value.

14. Widely distributed species are adapted to various habitat conditions by evolving ecotypes.

15. Every habitat has potential to support a certain number of organisms. This is known as *carrying capacity* of the habitat. Knowledge of carrying capacity is essential for proper management of the habitat.

16. The biotic and abiotic components of the environment are in constant flux in any habitat which induce ecological succession with the passage of time and change in the environment.

17. Sun is the only source of energy in our earth's environment and the life depends on solar energy. Organisms live through exchange of energy.

18. Energy is neither created nor destroyed. It can be transformed from one form to the other.

19. During transformation of energy from one form to the other a large amount is dissipated into the environment mainly as heat energy.

20. Every living thing that we see has potential energy in huge quantity. One gm dry weight of body tissue contains 4—5 kcal of energy stored in it.

21. Solar energy reaching the earth's surface is not lost but only transformed from one form to the other. A very small amount (1 to 3 per cent) of solar energy is trapped by green plants and converted into chemical energy.

22. Energy flow from the sun to the plants, to the other organisms and then to the space is always unidirectional.

23. Energy and space relationships of the organisms cause niche differentiation within the habitat which brings about ecological stability in the community life. In any habitat a community is born, it grows with passage of time and through succession it is stabilized to form a climax community.

24. Life on the earth exists in a thin mantle or layer around the earth. This layer forms the biosphere.

25. The biosphere is not uniform structure and it consists of several life supporting habitats called *ecosms* or *ecosystems.*

26. An ecosystem has *producers* (plants), *consumers* (animals), and *decomposers* constituting the *biotic component,* and life supporting matter and energy which constitute the *abiotic component.*

27. In any ecosystem the stability is conditioned by :

(*i*) fixation and transfer of energy in the organisms at various levels.

(*ii*) conversion of abiotic components (nutrients and energy) into organic structures which adds to the biomass. The abiotic components are replenished through weathering of the lithosphere, atmospheric movements and biogeochemical cyclings of nutrients.

28. Energy flow, synthesis of matter and balanced relationship of biotic and abiotic components in an ecosystem are regulated through ecological processes.

ENVIRONMENTAL OR ECOLOGICAL FACTORS

Ecological factors are many and diverse and often intricately mixed and interdependent. These factors either singly or in combination influence and determine the presence or absence, vigour or weakness and relative success or failure of various plant communities in a particular habitat.

The environment of an organism may be subdivided into physical (abiotic) and biotic components. The physical or abiotic environment of all organisms on the earth includes three main media which also act like factors, viz., atmosphere (air), lithosphere (soil) and hydrosphere (water) and a variety of other physical factors like light, temperature, pH etc. The study of abiotic factors and substances has been described as **environmental ecology**' by A.S. Boughey (1971). The environmental conditions which influence the life and development of organisms are grouped into four main classes which are as follows :

(1) Climatic factors (related to aerial environment);

(2) Edaphic factors (related to soil conditions);

(3) Physiographic (topographic) factors; and

(4) Biotic factors.

As already mentioned, these ecological factors are inter-related and intricately mixed. They work through one another acting and reacting together, as for example, the change in physiographic conditions at a place may bring about a change in local climate that, in turn, may affect the soil and competition impress.

CLIMATIC FACTORS

Climate is one of the important natural factors controlling the plant life. Its study is called climatology. The climate includes that following main factors :

(1) Light
(2) Temperature
(3) Precipitation and atmospheric humidity
(4) Air and atmosphere.

LIGHT

Light is the most essential abiotic factor without which no life can exist. It is non-lethal limiting factor both at the maximum and minimum levels. The chief natural sources of light are sunlight, moonlight, star light and the light producing or luminescent organisms. Of these sunlight has the greatest ecological significance.

The radiant energy coming from the sun in the form of visible spectrum is called light or luminous energy. Radiation that penetrates that earth's atmosphere consists of electromagnetic waves of a wide range in wavelengths. A beam of light is pictured as a shower of particles called *photons*. Each photon carries a certain amount of energy called *quantum*. The energy varies inversely to the wavelength of the spectrum. The solar spectrum in the earth's atmosphere has been analysed on the basis of wavelengths into different radiations (Fig. 2.1). The solar radiations which penetrate earth's atmosphere consist of a band of visible (to man) light and

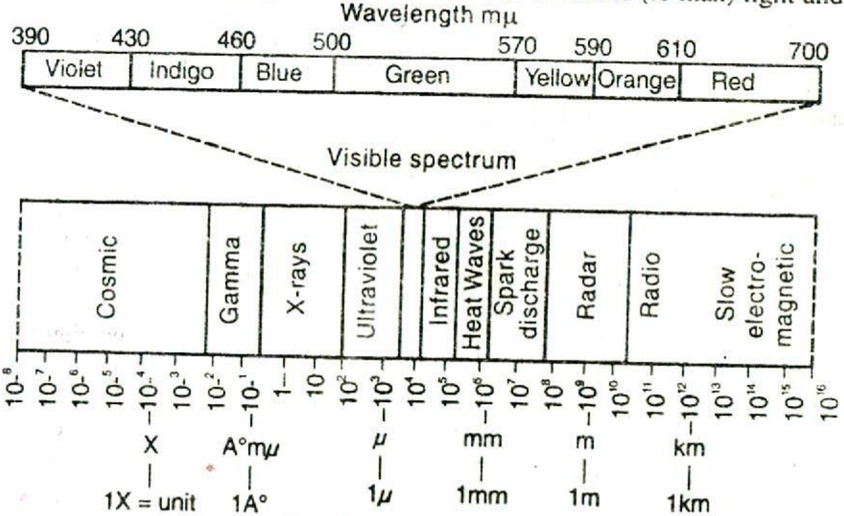

Fig. 2.1. Solar Spectrum

a small proportion of ultraviolet and infrared radiations. It is not known whether the long radio waves have some ecological importance to plants. The visible light lies in the range of 400—750 mμ. When the visible sun-light is passed through a prism it is dispersed into a series of wavelengths exhibiting seven different colours—*violet, indigo, blue, green, yellow, orange,* and *red* (VIBGYOR). The wavelength of ultraviolet (2% of the radiation reaching the earth surface) is below 390 mμ and that of infrared above 750 mμ (1 millimicron or mμ = 1/1000 of a micron). Since a micron is 1/1000 of a millimetre, a milliμ (mμ) is equal to ·000001 mm or 10^{-7} cm). In working with ultraviolet and other rays of shorter wavelengths Angstrom unit is used (10 Å = 1 mμ). The photochemical activity is greatest at the violet end. Ultraviolet (UV) thus, has the greatest killing effect on the protoplasm. It helps in the synthesis of anthocyanin in leaves and inactivates the growth hormones and thus checks stem growth. Microbes injured by ultraviolet rays are often rejuvenated by exposure to visible light. X-rays and γ-rays show high degree of ionising effects. They cause mutation in the living systems and in high doses they are absolutely fatal. Infrared radiations are not so powerful as may stimulate biochemical reactions. These radiations have high heating effects. They exert influence on stem growth and germination. The radiations of wavelengths shorter than 290 mμ never reach to the earth surface.

Light is usually measured by an electric instrument called lightmeter or photometer which consists of a light sensitive photoelectric cell. The intensity of light is directly recorded on a dial of the photometer. It is measured in foot candle or lux. Photometers are never exposed to direct sunlight. Actually, light reflected by a thick white paper placed on the ground for surface of the plant is measured. For ecological purposes light intensity is measured in a number of habitats for different species. This will enable one to know whether the species are shade loving or light demanders.

Spatial Variations in Light Intensity

Light intensity differs from place to place. The spatial variation in light intensity may be caused by the following :

(*a*) **Effecting atmosphere.** When the light passes through the atmosphere of the earth, a small proportion of radiations of shorter wavelengths become absorbed by atmospheric gases, mainly nitrogen and oxygen. The places at high altitudes receive brighter light than those at lower altitudes (above the sea level) because at higher elevations the atmosphere is thinner than that at low elevation.

Atmospheric vapour exerts a powerful screening effect and for this reason the intensity of light is much greater in dry areas than in wet regions. In a cloudy day, the light may be reduced to 4% of the normal intensity. When the atmosphere is saturated with fogs and clouds, a relatively high proportion of light rays of longer wavelengths, such as infrared and other visible radiations, are absorbed by the atmospheric moisture and the light rays of shorter wavelengths and ultraviolet rays are absorbed by the gas molecules and vapour droplets and the light reaching the earth surface under such conditions is called diffused light or skylight. The diffused light on overcast day comprises upto cent per cent of the total light and on clear day it may comprise about 10-15% of the total light. Latitudinal variations in light intensities due to the height of the sun above the horizons are very important. At the equator, the light is most intense and contains highest proportion of direct sunlight. Towards the poles, the intensity of direct light decreases and the percentage of diffused light goes high.

(*b*) **Effect of water.** In water medium, the intensity of light is reduced and this decreases progressively with the increase of water depth. About 10% of the sunlight falling on the water surface is reflected and 90% of that penetrates water and is modified in respect of intensity, spectral composition, angular distribution (refraction) and time distribution. Phytoplankton, zooplankton and suspended particles either reflect or absorb the light rays. Submerged plants get weaker lights than the plants on the surface of water get. It is so because a proportion of light falling on the water surface is reflected and the major part of the penetrating light is absorbed by upper layers of water. When light reaches on the surface of water the major proportion of rays of shorter wavelengths. *i.e.,* violet, indigo, blue and green, are reflected and other lights are partly absorbed. This is why bodies of water appear bluish green in colour. Reflection of light is increased several times in the rough water surface. There is a selective absorption of light at various depths in water. The rays of longer wavelengths are absorbed near the surface and in general light rays of shorter wavelengths penetrate deepest. Thus, infrared rays are absorbed in upper layers of water (about 4 meters); red and orange rays are completely absorbed upto the depth of 20 metres; yellow rays may penetrate upto 50 m and green and blue rays penetrate upto 80 to 100 m deep. Violet and ultraviolet rays penetrate upto 80 to 100 m deep. Violet and ultraviolet rays penetrate beyond 100 m depth and no light penetrates beyond 200 m depth.

Depending upon the penetration of light, oceans are divided into the following three zones :

(*a*) Euphotic zone (upto 50 m depth)

(*b*) Disphotic zone (80 to 200 m depth)

(*c*) Aphotic zone (below 200 m of depth)

In the oceans, algae are distributed according to wavelengths of light rays to which their colours are best suited to absorb and utilize : green algae are found in intertidal zone, brown algae descend somewhat deeper and red algae are characteristic of deep oceanic water.

Light has got sufficient power of penetration. Photosynthesis may take place in some plants which are covered under as much as 40 cm thick snow.

(*c*) **Effect of suspended particles.** Dust, smoke and other solid particles dispersed in the air or water have great screening effect. In smoky industrial cities, the smoke may reduce 90% of light.

(*d*) **Effect of the layers of vegetation.** In complex plant community, for example forest, the tallest plants receive full sunlight, undershrubs receive subdued sunflecks or diffused light, herbs and epigeous cryptogams grow in still weaker light. In dense forest the leaves completely check the penetration of light and less than 1% of total sunlight reaches the surface.

Temporal Variations in Light

The light intensity during summer is much higher than that in winter. It is weak at sunset in winter and comparatively stronger during the mid-day hours. This periodical fluctuation in the intensity of light is due to the change in the angles of radiations reaching the earth. When the sun is at the horizon the solar rays travel through approximately 20 times the thickness of the air they have to penetrate when the sun is overhead in the noon. At the equator, the day light prevails 12 hours out of every 24 hours in both the seasons, summer and winter. In the polar regions, the day length (photoperiod) becomes longer than 12 hours in summer and shorter than 12 hours in winter. The skylight or diffused light available before sunrise and after sunset is of great ecological importance. Moonlight plays some important role in the plant life. It sometimes satisfies light requirements of certain seeds, promotes starch hydrolysis in the leaves, affects nocturnal leaf movement in legumes, and stimulates the sexuality in certain marine algae.

Importance of Light to Plants

Earth is a very small object in the solar system and it receives only 1—50 millionth of the total solar radiation reaching the universe. The journey of solar energy from sun to earth surface is very much moderated while it passes through stratosphere and the atmospheric envelope surrounding the earth. In the stratosphere lies the ozone regions which absorbs the harmful solar radiations of short wavelengths. There are various devices to measure the solar energy. The unit of measure is erg or calorie and energy falling at a place is expressed in terms of cal/cm^2/min. At any place on the earth surface this energy flux varies with season, time of day and atmospheric humidity and drought. In the northern hemisphere solar energy falling at the outer surface of the earth's atmosphere is 0.485 cal/cm^2/min. This is taken as hundred per cent solar radiation. Of this only 0.228 cal/cm^2/min reaches the earth surface, *i.e.*, only 47 per cent of the radiation reaches the biosphere and the rest 53 per cent is scattered and lost (Gate, 1965).

From the ecological point of view, the energy and its utilization is most important for the existence of life. Many of the environmental phenomena like movement of wind currents, rainfall, chemical action and organic behaviour are controlled by energy.

There are three possible pathways for light to take when it reaches the surface of a plant or animal; it may be reflected from the surface, it may be absorbed by the surface and it may be transmitted through the material (Moen, 1973), Fig. 2.2.

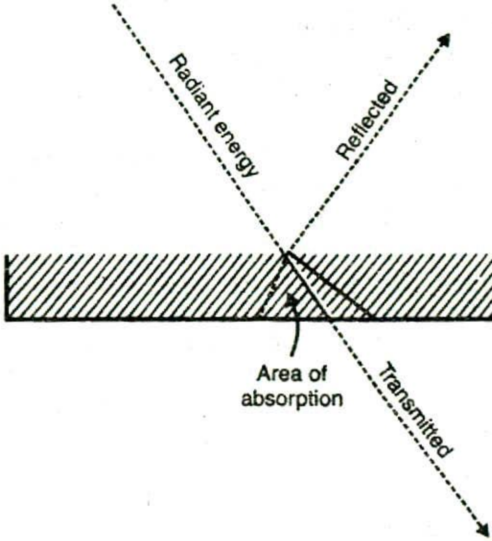

Fig. 2.2. Three pathways of solar radiation reaching the body surface.

Light affects many physiological activities of the plants. Light affects the following aspects of plant life :

1. **Photosynthesis.** Out of the total solar energy reaching the earth, only about 2% is used in photosynthesis and about 10% is used in other physiological activities. It has been estimated that a corn plant utilises only 0.13 per cent of light energy. All wavelengths of light are not utilised by a plant. Green light is completely reflected by green parts of the plants making them look green. Red and blue green are the two maxima of absorption of light. The green plants, the producers of ecosystem, synthesize their food (carbohydrates) from water and CO_2 in presence of sunlight. The solar radiations provide energy for this process. In this processes the radiant energy of sun available to the plants is converted into the chemical energy by chlorophylls. The chemical energy stored in food is utilised in various other biochemical activities of the plants. The rate of photosynthesis is greater in intermittent light than in the continuous light. The relationship of light intensity with photosynthesis in terrestrial as well as in aquatic plants follows the general pattern of a linear increase upto an optimum or saturation intensity followed by a decrease at high intensities (Rabinowitch, 1951; Thomas, 1955).

Light plays important role in the development of plastids and pigments. It has marked effect on the number and position of chloroplasts. The upper part of leaf which receives full sunshine has large number of chloroplasts which are arranged in line with the direction of light. At high intensity, the photo-oxidation of enzymes reduces not only the rate of carbohydrate synthesis but also that of protein synthesis. The protein synthesis is especially reduced by high intensity of light. High intensity of light, however, influences the formation of anthocyanin pigment. It is for this reason, alpine plants have beautifully coloured flowers.

2. **Respiration.** There is no direct effect of light on the respiratory activity in the plant body. Indirect effect is much important because in presence of light the respiratory substrates are synthesized. Under certain conditions, such as, in shade and under water, the light becomes a limiting factor and the photosynthesis is not sufficient for effective growth. Under such conditions, the rate of photosynthesis is just sufficient to meet the need of respiration. This is called *compensation point.* At this point, the dry weight of plant does not increase. The compensation point differs in different species and in different individuals of the same species at different ages. In many plants the respiratory rate increases with the increase in the light intensity. Ranjan and Saxena have studied the effect of light intensities on respiration rate in many plants and have shown that respiratory rate could increase in *Canna, Nerium* and *Bougainvillea* with the increase in light intensity. However, in some other plants respiration rates decreased slightly in intense light. The rise and fall of respiration rate may be due to the effect of light on the permeability of plasma membrane, change in the viscosity of the protoplasm and photo-oxidation of enzymes. The permeability and viscosity increase with the increase in light intensity up to certain optimum. Light, however, has got very little effect on respiratory process of lower plants and thallophytes.

3. **Opening and closing of stomata and in transpiration.** Mostly the stomata remain opened in the light and closed in the dark. Light brings about phosphorylation and conversion of starch into soluble sugars in the guard cells and thereby increases their osmotic pressure which, in turn, causes inflow of water in the guard cells. The increase in the turgidity of guard cells causes widening of gap between two guard cells. The opening of stomata increases the gaseous exchange and also increases the rate of transpiration during day period. Increase in the light intensity above the optimum shows detrimental effects because the increased transpiration in the intense light is injurious to plants.

4. **Growth and flowering of plants.** Light shows manyfold effects on the growth of the plants. Growth of plants depends especially on the intensity, quality, duration and direction of light. High intensity of light inhibits the production of auxins or growth hormones and consequently it influences the shapes and sizes of plants. Plants growing in darkness or insufficient light produce maximum amount of growth hormones as a result of which they are elongated with slender pale yellow stem and small leaves. The plant growth is slow in the light of high intensity. Red light favours the growth. Lights of shorter wavelength, except violet, are detrimental to plant growth.

Duration of light is also very important. Actual duration or length of the day (photoperiod) has been shown to be important factor in the growth and flowering of wide varieties of plants. The controlling effect of the photoperiod, known as photoperiodicity, is currently an active field of physiological ecology. According to their response tó photoperiods, the plants have been classified into three well defined groups :

(*i*) **Long day plants.** Plants which bloom when the light duration is more than 12 hours per day, as for example, radish, potato, spinach, etc.

(*ii*) **Short day plants.** Plants which bloom when the light duration is less than 12 hours per day, as for example, cereals, tobacco, cosmos, dahelia, etc.

(*iii*) **Day nuteral plants.** Plants which show little response to length of daylight, as for example, cotton, balsam, tomato plants.

Recently it has been shown that photoperiodic stimulus for flowering is also controlled by thermal points, Azzi (1957) has shown for the first time that initiation of flowering in a plant occurs at certain constant which is specific for a particular species. This constant is called Azzi's constant which is expressed as follows :

Azzi's constant = Total duration of light in hours
+ total means temperature in °C.

Chinoy (1960) has confirmed this constant and called it **Photothermal quantum** requirement of a species. Thus, an increase in temperature will decrease the duration of light required for flowering. This information can be applied to advantage in autecological studies of certain crop plants.

Plants which receive direct sunlight are called *heliophytes* and those growing in the shades are called *sciophytes*.

Heliophytes exhibit the following features :

(*i*) Stem with short internodes and long lateral organs;
(*ii*) Roots numerous and profusely branched;
(*iii*) Thick cuticle;
(*iv*) Well developed palisade and weakly developed spongy tissue in the leaf;
(*v*) Well developed xylem with thick rays;
(*vi*) Small intercellular spaces in the tissues;
(*vii*) High respiration rate and much rapid transpiration;
(*viii*) Vigorous flowering and fruiting;
(*ix*) Early appearance of flowers;
(*x*) Low chlorophyll content; and
(*xi*) Proper development of mechanical tissues.

In the absence of light, the growth is very poor and plants show etiolation. The stem becomes tender, narrow, and long and the leaves become pale green, soft and small. Thus, light is essential for the normal and healthy growth of plants.

5. **Movement.** Light affects the movement of some plants. The stems, roots and leaves show different responses to light. The effect of sunlight on the plant movement is called heliotropic effect. The stems elongate towards the source of light positively phototropic and the roots are negatively phototropic. The leaves grow transversely to the path of light. In order to receive maximum sunlight, the leaves are oriented on the stem in such a way that they do not overlap one another.

6. **Germination of Seeds.** The seeds when moist are very sensitive to light. In some cases, the germination of seeds is retarded in light. The quantity of light needed for the stimulation of embryo varies in different seeds.

In most cases, the red light promotes germination and far-red light inhibits germination. Investigations regarding the mechanism of seed germination in light have revealed that a pigment phytochrome is involved in this process. The pigment occurs in two reversible forms—Pr and Prf which develop under red and far-red light. The germination depends upon the balance between two forms :

$$\underset{\text{(Inactive)}}{\text{Pr}} \underset{730\text{ nm}}{\overset{660\text{ nm}}{\rightleftharpoons}} \underset{\text{(Active)}}{\text{Prf}}$$

Seeds of certain plants require blue light for germination. Germination of *Typha* seeds is promoted in yellow light. Yellow light counters the inhibitory effect of blue light.

Light is an important factor in the distribution of plants. Some plants grow in full sunlight, while others prefer to grow in shade. Bormann (1956) describes an interesting situation in certain species of pine in which young seedlings are shade adapted while older seedlings and young trees do not grow well in shades.

TEMPERATURE

Temperature is a variable factor which is influenced by time, season, latitude, altitude, slope, direction, soil texture, plant cover and human activities like urbanisation and industrialization. It penetrates every region of the biosphere and profoundly influences all forms of life by exerting its action through increasing and decreasing some of the vital activities, such as the metabolism, reproductive, behaviour, embryonic development and growth. Temperature is a measure of intensity of heat. In terms of standard unit it is commonly expressed as degrees either in Fahrenheit or Celsius scale (Centigrade). Heat is a from of energy called thermal energy. Thermal energy is exchanged between animal and environment by radiation, conduction, convection and evaporation. These four basic modes of transfer of heat energy occur within the organisms and in the interface between the organisms and their environment (Fig. 2.3).

The total amount of heat entering the biosphere from the sun is balanced by the amount lost per unit time. The flow of geothermal heat from the interior of the earth is small as compared to the amount of heat entering the biosphere from the sun. The estimate of thermal energy flow in the biosphere is referred to as *heat budget* (Vernberg and Vernberg, 1970).

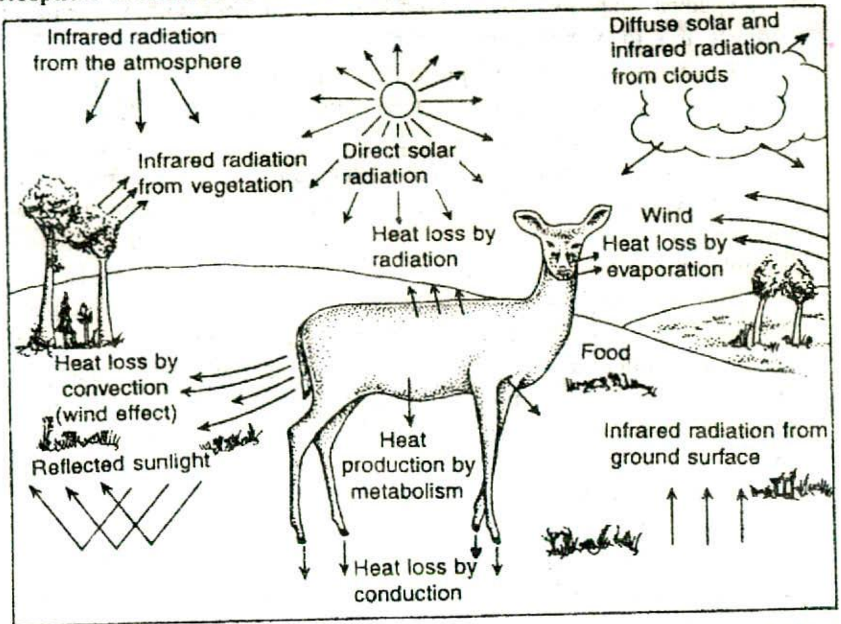

Fig. 2.3. Exchange of thermal energy between the organisms and their environment through radiation, conduction, convection and evaporation.

The most influential factors in the climate are temperature and moisture. The temperature affects the vegetation either directly or indirectly. Directly it appears in two ways :

(*i*) It affects the physiological processes of plants and consequently their growth and size; and

(*ii*) It determines which species can survive in a particular region. The different species of plants show a wide variation as regards their tolerance to temperature range and fluctuation.

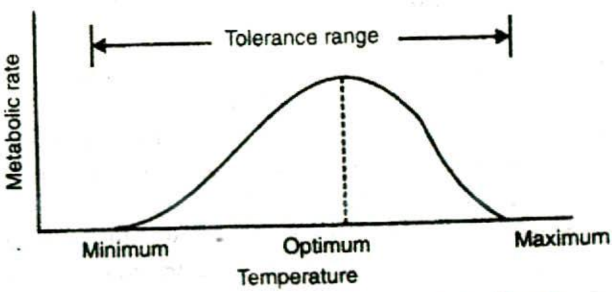

Fig. 2.4. Effects of temperature on the metabolic rate.

On our planet, organisms can carry on their life activities over a relatively narrow temperature range extending from 0°C to 50°C and every plant has a specific range of temperature requirement. This range differs from species to species. Plants do not thrive in places with higher or lower temperatures than their specific ranges.

Generally, at 40°C the protoplasm undergoes such changes as are minimal to plant life and it dies at temperatures above 90°C. However, some plants carry on their life processes at high temperatures but at 70°C temperature plants rarely survive. At temperatures below freezing point plants generally die because of rapid crystallisation of protoplasmic water which results in mechanical injury. Air dried yeast can endure temperature as high as 114°C. Bacteria can endure temperature between 120°C and 130°C. A few fungi can withstand temperature upto 89°C. Air temperature above 32°C is most favourable for tropical plants. Existence of vegetation has been recorded between 26°C (some conifers) and 66°C (desert plants). Every organism has a definite temperature range. The temperature at which all metabolic processes necessary for life can only initiate and proceed with lowest pace is said to be minimum temperature and increase in the temperature above the *minimum level* increases the rate of metabolic activities until they reach the maximum level at a temperature which is called *optimum temperature*. Further rise in temperature beyond optimum level brings about decrease in the metabolic rate until it ceases at a temperature called maximum temperature (Fig. 2.4).

The general inability of protoplasm to endure high temperature can be ascribed in large part to the sensitivity of its enzymes to heat. Catalytic proteins in nearly all cases are irreversibly inactivated by exposure to high temperatures (usually greater than 50°C) for any length of time. They are, however, able to withstand lower temperatures even below the freezing point of water. The ability of the cell to endure sub-freezing temperatures seems to depend principally upon the avoidance of ice formation. The appearance of ice crystals in cells is almost always associated with the death of the cells, due in part to mechanical damage inflicted on the subcellular structure by the ice crystals themselves. Death may also be due to removal of water from the protoplasm by ice formation in the intercellular spaces, thus dehydrating the protoplasm.

According to the heat requirement of plants, Raunkiaer divided the gross vegetation into the following types :

(*a*) **Megatherms.** These are the plants of warm habitat which require high degree of heat throughout the year. They are found in areas with tropical climates *e.g.*, plants of deserts.

(*b*) **Mesotherms.** These are the plants of habitat which is neither very hot nor very cold. These plants cannot withstand extremely high or low temperatures and they are found in tropical and subtropical habitats.

(*c*) **Microtherms.** These are the plants of cold or temperate habitat and require low temperature for their growth. Such plants cannot tolerate high temperature. They may also be found in tropical and subtropical areas at high elevations where temperature conditions are less extreme.

(*d*) **Hekistotherms.** These are the plants of cold and alpine regions. They do not thrive well in heat and can withstand long and very severe winter.

Many plants are very sensitive to temperature. The sudden fall in temperature is injurious because plant tissues are badly affected by it. Forests suffer from night frost on the east side where the sun rays strike very early in the day. As an adaptation against frost, the starch of plants changes to fats or oils in the autumn. The fatty oils depress the freezing point and thus increase the power of resistance in plants against frost. The leaves of plants in the coldest lands store fats. Pentosans, mucilage and pectic substances which have high water retaining power are abundant in many plants. They decrease the danger of plants from desiccation and consequent death. Dried seeds and spores are not affected by freezing because there remains no liquid in them that can freeze. Due to removal of water from seeds, the cold resistance of seeds of certain plants increases upto the extent that their exposure for 3 weeks to —190°C does not diminish their germinability.

The temperature stimulates the growth of seedlings. The optimum temperature for seed germination ranges between 20°C and 27°C.

The absorption rate is retarded at low temperature. Photosynthesis operates over a wide range of temperature. Most of the algae require lower temperature range for photosynthesis than the higher plants. The photosynthesis continues even at 80°C in some desert plants.

The rate of respiration increases with the rise of temperature upto a certain level, but beyond the optimum limit the respiration rate shows marked decrease. The rate of respiration becomes doubled at the increase of 10°C above the optimum temperature provided other factors are favourable (*Vant Hoff's law*). High temperature generally favours the growth of plants, but for some crop plants low temperature is beneficial. It the temperature ranges of winter varieties are lowered upto 0°C to 5°C, the seeds sown in the spring season will grow luxuriantly and the plants will mature and flower at normal time. The process by which temperature range of plant is lowered in order to get early crop is called *vernalization*. This practice is very common in cold countries.

Temperature determines the growth of many plants. Cotton prefers high temperature. Potato gives highest yield in low summer temperature. Growth of plants is retarded at high temperatures.

Temperature in combination with humidity and other factors helps in the spread of diseases in plants. Low temperature and high humidity favour the rust attack. Low temperature, high humidity and cloudy weather favour the damping off, seedling blight, foot rot and root rot diseases of cucurbits, tobacco, papaya and ginger.

Temperature fluctuation in environment. The environmental temperature fluctuates both daily and seasonally. Temperature in any locality is governed by the brightness of the sun. It may vary from sunlight to shade and from daylight to dark. Surface temperature in soil may be 30°C higher in the sunlight than in the shade and upto 17°C higher during day than that in the night. In the desert the temperature may be 40°C higher during day than that during night. The Thar desert in south Rajasthan may show diurnal change of temperature to the extent of 20 to 30°C.

Latitudes also affect the temperature cycles. With the increase of every 150 metre altitude the temperature decreases by 1°C, Different habitats such as fresh water, marine and terrestrial environments show varying response to fluctuating temperature. Temperature fluctuations are less in the aquatic environment than in the terrestrial one. The increase in depth of aquatic medium increases the temperature fluctuation. Minimum temperature of the sea may be —3°C while temperature of fresh water pond never goes below 0°C. The maximum temperature of ocean generally reaches up to 36°C but it may go much higher in fresh water ponds and pools. In deep bodies of water heating or cooling is restricted to surface layer but deeper layers may also get heated or cooled as a result of vertical circulation wherein surface water is brought to the deeper regions and vice verse. Studies on the vertical fluctuations of temperature have led to the hypothetical classification of fresh water media into the following layers :

1. *Epilimnion*—This is the superficial layer of body of water which is constantly stirred by wind and is a layer of warmer water.

2. *Metalimnion* or *Thermocline*—This is the intermediate zone between the upper and bottom layers of body of water. This layer shows vertical temperature changes.

3. *Hypolimnion*—This is the bottom layer of stagnant water with little or no fluctuation in temperature. The process of differentiation of fresh water habitat on the basis of vertical changes of temperature into three strata is referred to as **thermal stratification**.

In terrestrial environment temperature fluctuations are varied and marked. Lowest temperature recorded for any land mass is —70°C (Siberia, 1957). Higher temperatures may often reach upto 85°C in deserts at noon. In Rajasthan the highest temperature exceeds 50°C. Water in hot springs and geysers may be as high as 100°C.

The temperature varies from place to place and likewise the vegetations of different areas also differ considerably. Desert plants grow in extreme heat, aquatic plants grow in low temperature range, and grasses prefer to grow in the area of moderate temperature.

Temperature in combination with moisture determines the general distribution of vegetation. Northern, southern, tropical and temperate vegetations depend solely upon temperature and moisture.

PRECIPITATION AND ATMOSPHERIC HUMIDITY

Water is one of the most important climatic factors. It affects the vital processes of all the living beings. It is the plenary agent that sets in motion the nutrients of the soil and makes them available to plants. It affects the morphology and physiology of the plants. It in combination with other factors regulates the structure and distribution of plant communities.

In nature, water may be found in vapour, liquid and snow or ice states. In the atmosphere, water is found in the form of vapour. The quantity of water retained in the atmosphere depends on temperature and wind. Vapour increases in the atmosphere if the temperature rises and pressure decreases. At certain temperature and pressure, the maximum water-laden air is called saturated atmosphere. At saturation point, if the temperature is lowered the water holding capacity of atmosphere is reduced which causes the condensation of water vapour in the form of rain drop, dew, frost, sleet, snow, etc. This is *precipitation*.

The water vapour present in unit volume of air is called *absolute humidity*. This is expressed in terms of percentage of water vapour present in unit volume of air at certain temperature. The amount of water vapour required to saturate the same unit volume of air under constant physical conditions is called *relative humidity*.

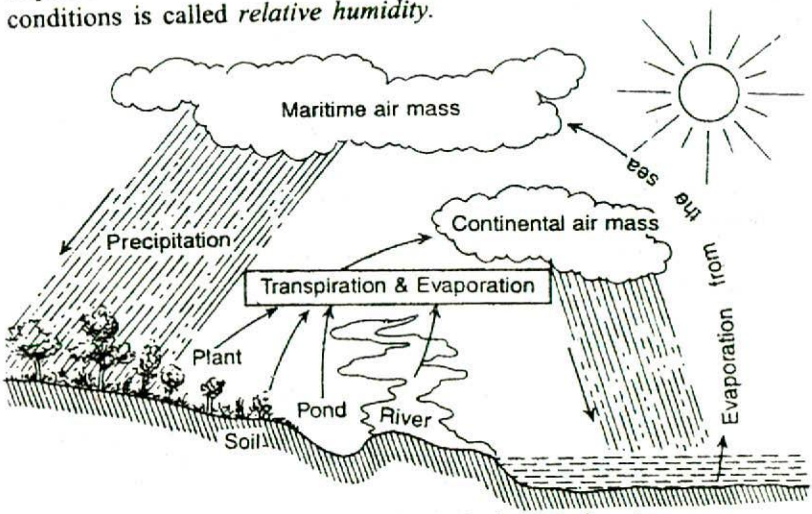

Fig. 2.5. Hydrologic cycle in nature

Water of atmosphere reaches to the earth's surface through precipitation and from earth's surface it reaches to the atmosphere through evaporation and transpiration (Fig. 2.5). Thus, a continuous circulation of water from earth to atmosphere and *vice versa* is maintained in nature. This is called *water cycle* or *hydrologic cycle*. It has been estimated that about 80,000 cubic miles of water from the oceans and 1,500 cubic miles of water from lakes and land surface evaporates annually. The total evaporation is equalled by total precipitation of which about 24,000 cubic miles of water falls on land surface. The main source of water for terrestrial plants is rain water. Penck using precipitation-evaporation ratio, has classified the climate as follows :

(*i*) *Arid* — It is characterised by the condition in which evaporation is greater than precipitation.

(*ii*) *Arid-humid* — When evaporation is more or less equal to precipitation.

(*iii*) *Humid* — When evaporation is lesser than precipitation

The total rainfall, especially the distribution of rainfall throughout the year is one of the leading features of climate. Rainfall map of the world corresponds very closely with the distribution of great vegetational zones of the world.

Sudden and heavy rains are not so beneficial as are moderate and continuous rains because in the heavy rains a large amount of water is lost from the surface of soil as run off and the soil is eroded.

Rainfall is determined largely by geography and pattern of large air movements of weather systems. When the moisture laden winds blow from the oceans towards the high mountain they deposit most of the moisture on the ocean-facing mountain slopes with a resulting 'rain shadow', and produce desert on the other side. The higher the mountain the greater is the precipitation of moisture over it. This is the main reason why deserts are usually found behind high mountains. The deserts are also found along the sea coasts, where wind blows from large interior dryland areas rather than off the ocean.

The amount of rainfall in different localities largely determines the nature of vegetation therein. The following tabulation gives a rough idea about the plant communities that may be expected in regions with different amounts of annual rainfall.

Annual rainfall	*Vegetation*
1. 0 to 13.24 cm	Desert
2. 13.25—35.1 cm	Semi-arid grassland
3. 35.2—63.5 cm	Dry subtropical grassland, savanna (a grassland with scattered trees or scattered clumps of trees—a community type intermediate between grassland and forest) and open woodland
4. 63.6—114.3 cm	Humid subtropical forest
5. 114.4—203.2 cm	Tropical rain forest

Snow, which may lie on the ground to form a valuable protective blanket and also a reserve of water is apt to limit the growing season by its late melting.

Hail, a special type of precipitation during the summer season in the form of small ice pieces, may cause serious injuries, especially to young crops.

Dew and sleets make a very vital contribution to precipitation in the regions of low rainfall. Dew and ground fog may be important to plants not only in coastal forests but also in deserts near the sea coasts where they provide much of surface water on which the ephemeral plants depend.

The atmospheric humidity influences directly the form and structure of the plants. It directly affects the transpiration rate of the plants. In dry atmosphere transpiration rate increases and as a result of this the water content of the leaf tissues decreases and the leaves wilt temporarily. Water requirements of different plant species differ considerably. Some species, on one extreme, thrive well in the region with an annual precipitation of 10 cm while some, on the other extreme, grow only when they are submerged in water. On the basis of their water requirements, the plants are grouped into three ecological groups :

(*i*) *Hydrophytes.* Plants adapted to aquatic environment.

(*ii*) *Xerophytes.* Plants adapted to grow in dry lands where water content is low.

(*iii*) *Mesophytes.* Plants living in the habitat that usually shows neither an excess nor a deficiency of water.

The actual effects of water on the plants may be complicated by other conditions, such as temperature and atmospheric humidity. The combination of temperature and precipitation plays vital role in determining the broad features of plant distribution on the earth surface.

The temperature exerts more limiting effect on the organisms when the moisture conditions are at extremes (*i.e.*, either very high or very low) than when such conditions are moderate. Likewise moisture also plays a more critical role at the extreme temperature. Some modern climatologists taking into consideration the quantitative measures, effectiveness and seasonal distribution of moisture and temperature have classified the climate into temperate, tropical, polar and high altitude climates. The characteristic features of these climates and peculiar type of vegetations restricted to them are given in the following chart :

Climate	*Characteristic features of climate*	*Vegetation*
1. Temperate climate	Cold and moist with well marked seasonal and diurnal fluctuation, average annual rainfall more than 762 mm (30″), warmest month temperature above 10°C.	Luxuriant vegetation in favourable situation. Trees and shrubs dominant, and herds exceeding trees and shrubs in number.
2. Tropical climate	Warm and widely humid with mean temperature of the coldest month usually 17.8°C and rainfall very heavy (200-400 cm per annum). Frost and snowfall are usually unknown. Little or no seasonal variation.	World's luxuriant rain forests in the regions of high rainfall. Scrubs, grassland, desert community in the regions of decreasing rainfall.

Climate	*Characteristic features of climate*	*Vegetation*
3. Monsoon area	It is characterised by dry and wet seasons. Rainfall very heavy.	Deciduous trees and shrubs.
4. Climates of polar regions and high altitudes.	Warmest month below 10°C. Precipitation mostly in the form of snow and widely distributed. Annual rainfall less than 254 mm (10″). Owing to low temperature, the relative humidity is high and evaporation rate is low. In the regions of high altitudes there is continuous light in summer and darkness in winter.	Vegetation mostly low and scant. Dwarf shrubs and grasses dominant. Mosses and lichens are common.

ATMOSPHERE AND AIR

The earth is enveloped by a gaseous layer called atmosphere. Gaseous mantle forming atmosphere extends into outer space some 1000 km or so above the earth surface. It maintains contact with all the major types of environment of earth, interacting with them and greatly affecting their ability to support life. It is a reservoir of several elements essential to life. It serves many functions including the filtration of radiant energy coming from the sun, insulation from heat less at the earth surface and stabilization of weather and climate owing to heat capacity of the air.

Structure of Atmosphere

There are five concentric layers within the atmosphere which can be distinguished on the basis of temperature (Fig. 2.6). These are as follows :

1. Troposphere
2. Stratosphere
3. Mesosphere
4. Thermosphere, and
5. Exosphere.

Troposphere. The lowest layer of atmosphere in which man and other living organisms live is called troposphere. Troposphere is about 20 km above the earth surface. It is thin in the polar regions (about 10 km thick). It is a mixture of several gases. The proportion of gases in the atmosphere is fairly constant. Troposphere is characterised by steady decrease in temperature and it may decrease upto —60°C in the upper layers. The composition of troposphere excepting water vapour and dust particles is presented in the table below :

Constituent	*Percentage by volume*
Nitrogen	78.0841
Oxygen	20.9476
Carbon dioxide	0.318

Constituent	*Percentage by volume*
Argon	0.2340
Neon	0.001818
Helium	0.000524
Methane	0.0002
Nitrous oxide	0.00005
Krypton	0.000114
Hydrogen	0.00005
Xenon	0.0000087
Ozone	0.000001

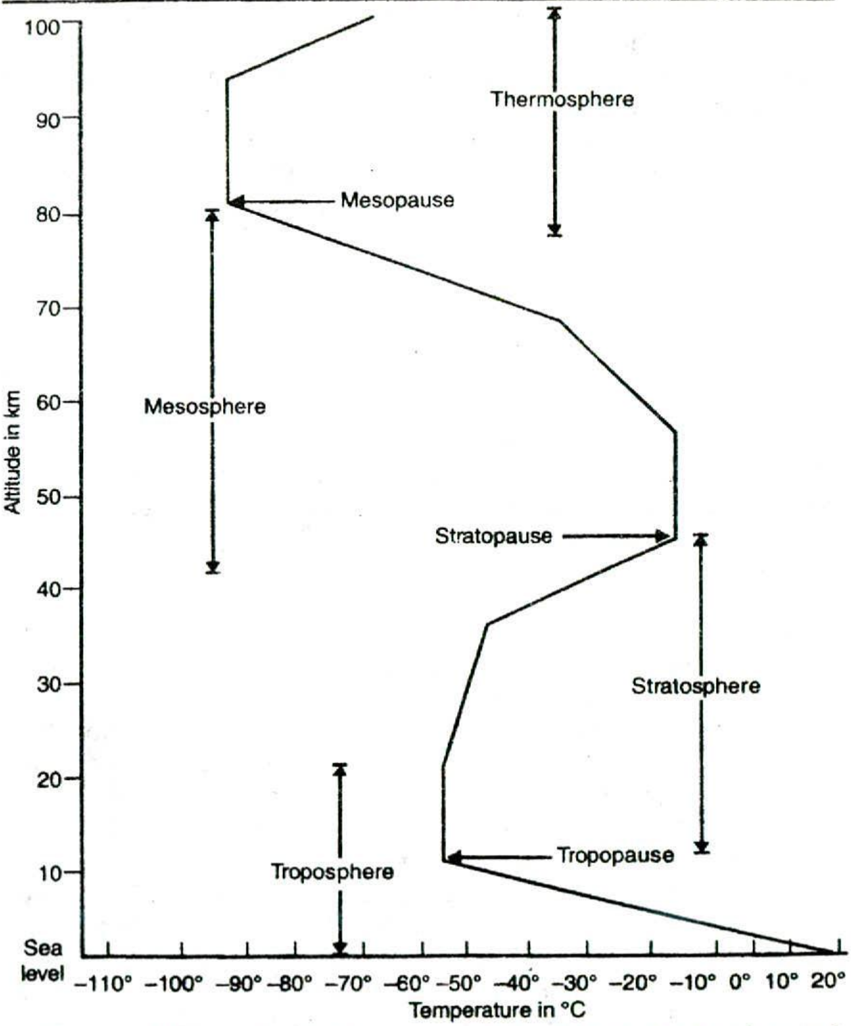

Fig. 2.6. Diagram showing the extent of different layers of atmosphere and temperature stratification of the atmosphere

The water vapour and dust particles occur in troposphere in variable concentrations. Concentration of water vapour may range from 0 to more than 4 per cent. The amount of water vapour in troposphere is maximum in the lowest level of atmosphere and it decreases gradually in the upper region and is entirely absent above 8 to 10 km. Dust is limited to lower levels and has no specific relationship with any other feature of atmosphere. Troposphere is the layer of sulphates and is the region of strong air movements, cloud formation, lightning, thundering etc. The upper layer of troposphere which gradually merges with the next zone or stratosphere is called is called *tropopause.*

Stratosphere. The second layer of air mass extending about 30 km above tropopause is called stratosphere. The uppermost layer of stratosphere is called *stratopause.* In this zone the temperature shows an increase from a minimum of about —60°C to a maximum of about 5°C. The increase in temperature is due to ozone formation under the influence of ultraviolet rays of solar radiation. Ozone is formed from oxygen by a photochemical reaction in which solar energy (symbolised as *hv*) splits the oxygen molecule to form atomic oxygen which then combines with oxygen molecule to form ozone

$$O_2 \xrightarrow{hv} 2O \quad \text{(atomic oxygen)}$$
$$O_2 + O \rightleftharpoons O_3 \quad \text{(ozone)}$$

The above reactions are reversible. Ozone content of stratosphere is constant which means that ozone is being produced from oxygen as fast as it is broken down to molecular oxygen. Ozonosphere is important because it absorbs ultraviolet radiations of the sun. The fact that upper region of stratosphere becomes warmer with increasing distance from the earth is due to transformation of absorbed ultraviolet rays into heat (Craig, 1968). The absorption of ultraviolet radiation by ozone umbrella is of paramount importance in the ecosystem because these radiations are prevented from reaching the earth surface where it would be lethal to living organisms. Ozonosphere also acts as a blanket that reduces the cooling rate of earth.

Mesosphere. It is the third layer of atmosphere next to stratopause. It is about 40 km in height. This region is characterised by low atmospheric pressure and low temperature. The temperature begins to drop from stratopause, goes on decreasing with the increase in the height and reaches a minimum of about —95°C at a level some 80 to 90 km above the earth surface The upper limit of the mesosphere is termed *mesopause.*

Thermosphere. Next to mesosphere is thermosphere which extends upto 500 km above the earth surface and is characterised by steady temperature increase with the height from mesopause. The thermosphere includes the regions in which ultraviolet radiations and cosmic rays cause ionization of molecules like oxygen and nitric oxide. This region is called *ionosphere.* In ionosphere, molecules of gases are so widely spaced that high frequency audible sound are not carried by the atmosphere.

Exosphere. The rest region of atmosphere above the thermosphere is called exosphere or outer space which lacks atoms except those of hydrogen and helium. This extends upto 32190 km from the earth. Exosphere has a very high temperature due to solar radiation. The earth's magnetic field becomes more important than gravity in distribution of atomic particles in the exosphere.

Air is an Ecological Factor

The gaseous mixture present in the troposphere is called air. Air moving from high pressure to low atmospheric pressure is called wind. It is an important ecological factor of the environment and it affects plant life mainly on flat plains, high altitudes in mountains and along the sea cost. Wind is directly involved in transpiration, causing various types of mechanical injuries and helps in dispersal of pollen, fruits and seeds. It also modifies the water relations and light conditions of a particular habitat through its effect on evaporation. It plays both positive and negative roles in atmosphere, for instance it has drying effect upon soil and may occasionally act in opposite direction bringing in moist air that reduces the transpiration and evaporation and may actually lead to the deposition and precipitation of moisture.

Effect of Air on Vegetation

The following are the important effects of wind on vegetation :

(*i*) Wind increases the water loss by constantly removing the air saturated with water vapour from the intercellular spaces of the leaves and bringing unsaturated air in contact with leaves and young shoots.

(*ii*) Mechanically, wind causes erosion of soil and abrasion of vegetation through removal of particles. Physiologically, it decreases the growth of plants by way of reducing the moisture content of air and reducing the turgidity of plant parts on which it impinges. Moist air promotes the growth of mesophytes.

(*iii*) In strong dry and hot winds, young parts of plants may become shrivelled and killed in a few hours and the surface of soil may become dry.

(*iv*) In open situations, *e.g.*, seashores and high mountain tops, where the strong winds blow all the year round in one direction, the trunks and branches of trees are twisted chiefly in the direction of prevailing wind. In such plants, generally, the growth of buds becomes checked on windward side (Fig. 2.7).

(*v*) In strong winds, big trees are uprooted and small plants and grasses are affected but to a very little extent. By strong wind, weak plants like wheat, maize, sugarcane, jowar, etc., are bent against the ground. These lodged plants, if their stems are not too mature, may become partially erect. This is due to differential growth of the meristematic lower nodes of these plants.

(*iv*) Wind is an important agent for the dispersal of pollen grains, fruits, seeds and spores of the plants. In deserts, the strong wind carries the sand and seeds. Thus, it plays important role in local distribution of plant species or communities of plants. Some types are wind resistant but some may be totally dependent on wind for their dispersal. Many plants are unable to flourish or even exist in the exposed situations if they are brought to such places by wind. Strong wind causes injuries to plants growing at high altitudes. In desert, the storm results in big sand-dunes which cover the vegetation (Fig. 2.8).

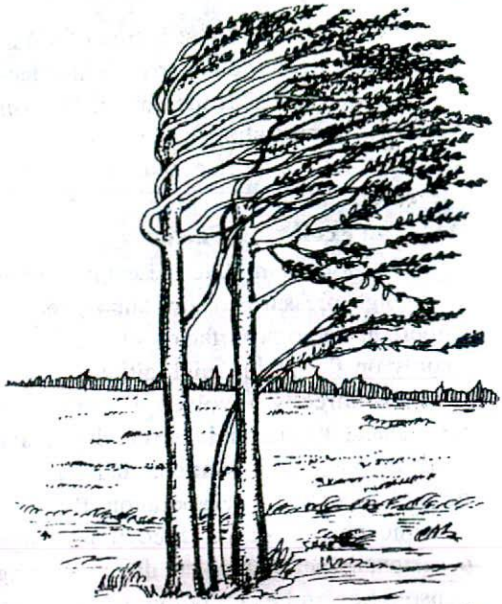

Fig. 2.7. Figure shows the effect of abrasive ice particles and strong winds on the branch growth. The buds on the windward side are either killed or they grow opposite the windward side.

Fig. 2.8. A view of sand dunes in the desert

(*vii*) In the areas subjected to strong winds, the leaves of plants become small and rolled. The transverse section of stem shows eccentrically developed secondary wood, *i.e.*, the diameter of the trunk in the direction of wind becomes greater than that at rightangle to it. The plants in such areas show extensive development of mechanical tissues which provide mechanical support and save the plants from wind injuries.

In India and many other countries of the world, unchecked winds have caused total disappearance of vegetation at certain places and rendered big areas deserted. Rajasthan desert in India is spreading eastward due to unchecked wind erosion.

MICROCLIMATE OR MICROENVIRONMENT

The important climatic factors, such as temperature, moisture, light and others show not only the regional variations but also the local, horizontal, and vertical differences. The organisms occupying the same general habitat may actually be living under varied conditions. The term 'microclimate' or 'microenvironment' refers strictly to combination of local atmospheric factors differing from the prevalent general climate (macroclimate) of the region. This is owing to the uneven topography, plant cover, etc. The microclimates are recognisable only in a very small area and they are sufficient to induce marked local variations in type and composition of flora. Thus, microclimate is of great ecological importance in the studies of plant and animal behaviour.

In one macroclimatic region there may eixst a number of microclimates differing in several respects from the general climate, as for example, in a dense forest tall trees are exposed to high intensities of light and temperature, but shrubby plants growing in the shades of trees do not get the same climatic conditions or in other words those shrubby plants grow in the environment of dim light, high moisture and low temperature, and again at ground level the conditions are changed so much that only some peculiar shade loving plants can thrive in them. Thus, it becomes very clear that climatic conditions of a particular region vary at different levels, both vertically and horizontally.

Puri (1960) has summarised a good deal of informations on microclimates of plant communities. A number of physiological experiments can be conducted but nowadays emphasis is laid on work under controlled conditions. At some places phytotrons and climatotrons are used for such studies which constitute a series of chambers with devices to control different factors of climate. These experiments are useful in knowing the exact climatic requirements of a particular plant and defining the role of each factor. Although it is not easy to work out the effect of environment as a whole yet the results obtained by the study of individual factors if coordinated may provide important conclusions.

Importance of microclimate is realised in modern trends in agronomy and soil conservation. Interplay of variations in microclimate and soil conditions results in marked variations in agricultural potentiality within short distances.

SOIL

Earth is a spherical planet of the solar system. It is differentiated into three main layers—crust, mantle and core. The core is the central portion of the earth containing nickel and iron in molten or vapourised state. This is about 2500 km from the centre. The mantle is the middle layer of the earth which extends about 2900 km above the core. The mantle is in molten state. The crust is the outermost solid zone of the earth which is about 9 to 40 km thick. The crust is very complex in composition and its surface is covered with the soil which supports rich and highly diversified biotic communities (Fig. 2.9).

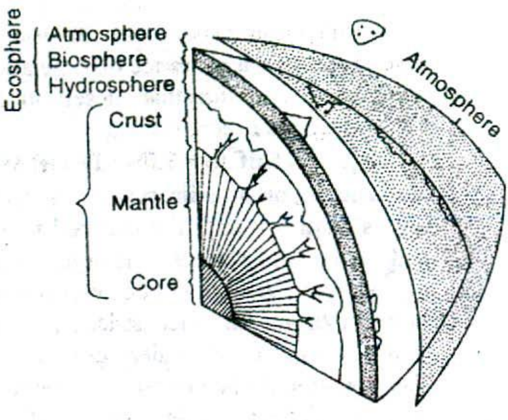

Fig. 2.9. Cross section of earth showing different regions.

The soil is one of the most important ecological factors called **edaphic factors**. It is the most characteristic feature of the terrestrial environment. It is the reservoir of biogenic salts and minerals which are essential for the living organisms. It is the outermost layer of earth's crust and is being constantly formed through weathering of rocks. It is not only a factor of the environment but also a product of the organic activities causing the biological weathering of rock.

Soil is defined as the unconsolidated top or superficial layer of earth's crust lying below any aerial vegetation and undecomposed dead organic remains and extending down to the limits to which it affects the plants growing about its surface. Beneath the soil, lie the subsoil and unweatherd rocks.

Edaphic factors are those which are dependent on the soil as such— on soil constitution, soil water, soil air, soil organisms and so forth. Soils at different places vary considerably in their structure, components and properties. These differences in the soils are often largely responsible for differences in vegetation within the same climatic region, and consequently they are of great significance in the distribution of plant communities.

Soil is a stratified mixture of inorganic and organic materials. The inorganic or mineral constituents of soil are derived from some parent materials, the soil forming rocks by fragmentation or break-down or weathering and the organic constituents of the soil are formed either by decomposition of dead remains of plants and animals or through metabolic activities of living organisms present in the soil.

Weathering of rocks is the initial steps of soil forming process which is brought about by (*i*) physical factors like temperature, water, ice, gravity and wind, (*ii*) chemical factors like solvent action, hydrolysis, oxidation, reduction, carbonation and hydration, and (*iii*) biological factors. Soil which is formed from the products of weathering processes is called embryonic or primary soil. It may mature into the following types of soils :

(*i*) **Residual or sedimentary soil.** This is the mature soil lying immediately over the parent rocks.

(*ii*) **Skeletal or immature soil.** This is only partly weathered material lacking maturation.

(*iii*) **Transported or secondary soil.** The transported soils are those in which the parent materials have been shifted to different places by the agency of glaciers, streams and rivers (**Alluvial soil**) the gravitational forces as landslides (**Colluvial soil**), wind (**Aeolian soil**), sand storms (**sand dunes**), standing water and wave action (**Lacustrine soil**) and oceanic waves (**marine soil**).

The second important process involved in the soil formation includes addition of organic matter, humification and mineralization. Organic matters are added to the embryonic soil by various living organisms. Plants and animals living in and on the soil after their death are decomposed and the decomposition product is mixed with the soil. All organic plant debris fallen recently to the ground is called ***litter***. The litter is composed of dead leaves, twigs, wood, dead roots and various plant products. Just below the fresh litter often occurs the material derived from preceding season's litter in which decay or microbial decomposition has set in. This is called ***duff***. The litter is decomposed by soil microbes such as bacteria, actinomycetes and other fungi. The products of decomposition include various types of inorganic and organic plant nutrients. They are all incorporated into mineral particles which then become dark in colour. The residual finally divided amorphous, incompletely decomposeds black coloured organic matter added to the mineral matter of the soil is called humus and the process of its formation is referred to as ***humification***. Humus includes two types of organic matter : the partially decomposed organic matter derived from litter and excreta of soil animals like centipedes, millipedes, earthworms, mites, grass-hoppers, etc. which feed on the litter of plant material. Gradually the humus is completely decomposed into simple compounds like carbon dioxide, water and minerals salts by a process called ***mineralisation***.

Depending upon the organic content, soils are generally classified as follows :

(*i*) *Mineral soils* which are rich in mineral particles.

(*ii*) *Peat and much* which are rich in organic matter in wet areas.

(*iii*) *Mors* which are low in basic minerals.

(*iv*) *Mulls* which are rich in base contents.

Muller (1879, 1884) has recognised two kinds of humus : *mor* and *mull*. **Mor humus** is acidic, abounds in fungi and is low in bacterial content. Fungul mycelia may help to bind together particles of humus and decomposing litter into matted layers. A well developed mor can be differentiated into the following three layers :

1. **Surface litter or L-layer** composing undecomposed leaves and twigs.

2. **Fermentation or F-layer** in which decomposition has proceeded some way towards development of humus. This layer is just below the L-layer.

3. **Humus or H-layer** which is found just below the F-layer. In this layer degraded humus fraction is accumulated. ***Mor*** is deficient in calcium and it develops on sandy soil under conifers. ***Mull*** is, on the other hand, slightly alkaline or neutral and abounds in bacteria. It does not show layer differentiation because of abundance of earthworms which promote mixing of organic and mineral materials. Intermediate between two types of humus is *moder* which has a richer and varied fauna.

Soil Profile

Soil profile is the term used for the vertical section of mature soil upto the parental material to show different layers of soil.

Soils commonly become stratified into layers or horizons at different depths. The layers of soil at different depths show different compositions and natures. Normally three main horizons or groups of horizons can be recognised. These are the upper horizons or **'*A*' horizon**, the middle horizon or **'*B*' zone** and **'*C*' horizon** (Fig. 2.10). Some workers recognised an additional horizon called **organic** or **'*O*' horizon** above the *A* horizon. These horizons are often divided by the use of appropriate subscripts such as O_1A_1, O_2A_2, A_3, and so on. **'*A*' horizon** designates the top stratum which is subjected to marked leaching. It is a layer of greatest biological concern as the plant roots, small animals, and microflora and fauna are found here most densely. In this zone the concentration of the organic matter is highest, and hence it is the dominant reservoir for plant nutrients.

The ***B* horizon** or the **subsoil** lying under *A* horizon has little organic matter, very few plant roots and a sparse microflora and fauna. In it, iron and aluminium compounds are often accumulated. *A* and *B* horizons collectively represent the true soil. At the bottom of profile is the *C* horizon which contains the parent materials of the soil. In this layer the organic matters are present in small amounts and little or no life is noted.

The essential components of most garden soils are as follows :

(*i*) Mineral particles of variable sizes obtained by weathering or breakdown of the rocks : 40—50% by volume and 95% by weight.

(*ii*) Soil water : 5.30%;

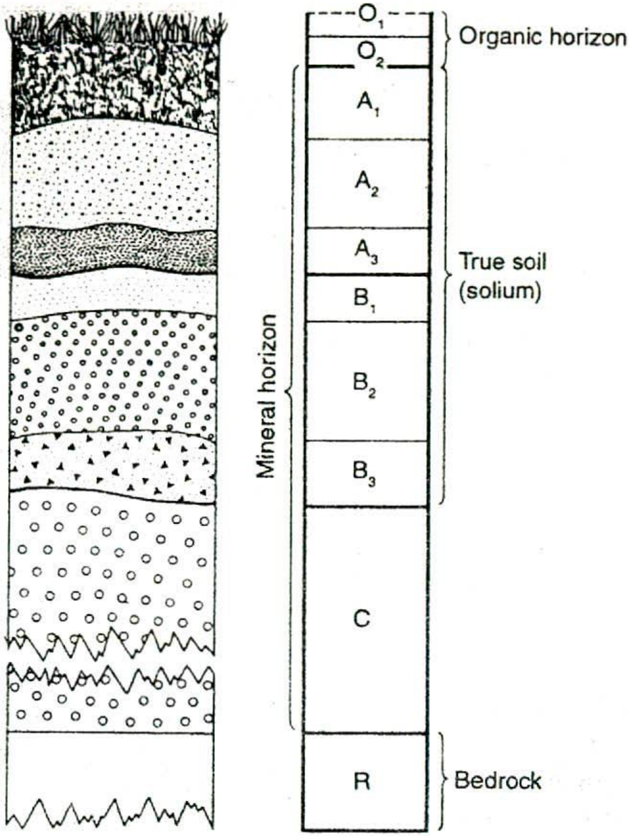

Fig. 2.10. A generalized profile of soil. O_1 : Loose leaves and organic debris; O_2 : organic debris partly decomposed or matted; A_1 : A dark coloured horizon with a high content of organic matter mixed with mineral matter; A_2 : A light coloured horizon of maximum leaching; A_3 : Transitional to B but more like A than B ; B_1 : Transitional layer but more like A than B_2; B_2 : A deeper coloured horizon of maximum accumulation of clay minerals or of iron and organic matter; B_3 : Transitional to C; C : Weathered material (regolith) : R : Consolidated bedrock.

(*iii*) Soil air or soil atmosphere : 25–30%;

(*iv*) Organic matter or soil humus arising from the death and decay of the parts of plants and animals or added manures : 1 to 5% by weight.

(*v*) Soil organisms, including both soil flora and soil fauna, as for example, protozoa, nematodes, earthworms, bacteria, fungi, algae, etc. Fig. 2.11 gives a rough idea about the percentages of various components of garden soil.

The important edaphic factors which affect the vegetation are as follows :

(*i*) Soil moisture;
(*ii*) Soil reactions;
(*iii*) Soil nutrients;
(*iv*) Soil temperature;
(*v*) Soil aeration or soil atmosphere; and
(*vi*) Biotic components of the soil.

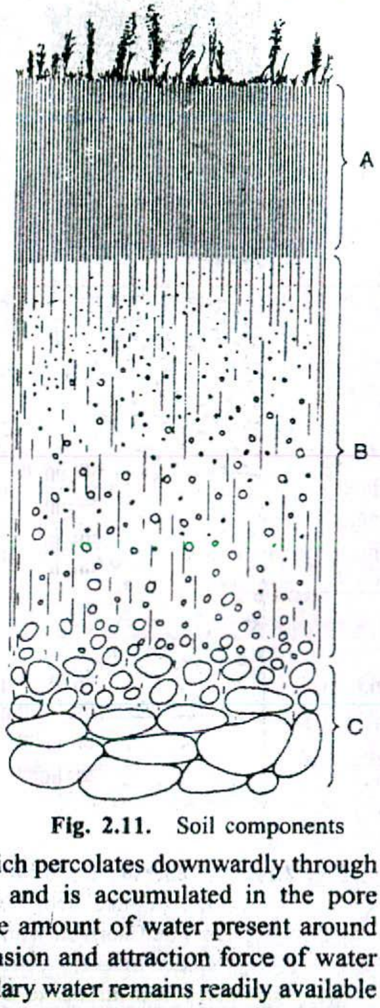

Fig. 2.11. Soil components

(*i*) **Soil moisture.** Plants absorb a small quantity of rain water and dew directly but they take a large quantity of water from the soil. Water held in the soil is found in the following forms (Fig. 2.12) :

(*i*) Gravitational water;
(*ii*) Capillary water;
(*iii*) Hygroscopic water;
(*iv*) Water vapour;
(*v*) Combined water.

Gravitational water is free water which percolates downwardly through the pore spaces between soil particles and is accumulated in the pore spaces in the form of *ground water*. The amount of water present around the soil particles and held by surface tension and attraction force of water molecules is called *capillary water.* Capillary water remains readily available to the roots upto a certain soil moisture tension. Water which is adsorbed on the soil particles and held on the surface of particles by forces of attraction and cohesion of its molecules is called *hygroscopic water*. This is the moisture remaining in air-dry soil. It cannot be used by the plants. The soil atmosphere, like external atmosphere, also contains moisture in the form of *water vapour.* Water of chemical compounds is called *combined water.* Total water content of the soil is called *holard.* Water of the soil which is easily available to the plant is termed as *chresard* and water which is so strongly held by the particles as to be unavailable to the plants is termed as *echard.* The availability of soil moisture is influenced by many conditions, such as distance of water table from the soil surface, the rate at which water percolates downward, the sizes of soil particles, the amount of annual rainfall, and the distribution of precipitation throughout the year. Water tends to promote the stratification of soil. Soil's available water is the chief factor responsible for local differences between plant communities. Heavily water logged soil is injurious for the growing plants because heavy accumulation of water in the soil reduces the soil aeration. Low water content in the soil is also injurious because it causes either temporary or permanent wilting of plants. Soil water is not only important in connection with direct fulfilment of water requirements of plants but it is also the medium by which mineral salts essential in the nutrition enter the plants in dissolved state.

(*ii*) **Soil reaction.** This edaphic factor influences the growth and distribution of the plants. The soil may show acidic, alkaline, or neutral reactions. The growth and productivity of many species of plants are critically related to soil acidity. Species of *Rhododendron,* cranberris are acid loving. Most of the field crops, such as barley, maize, soybeans, tomato, rye, potato, flourish in slightly acidic soils. Many ferns and beech trees thrive best in slightly alkaline soils. Soil acidity is important in many ways; in the behaviour of soil solutes, and in the relation of roots to the soil. Soil acidity affects the availability of iron, manganese, phosphate and other ions. In the acid soils, iron and manganese are available in appreciable quantities, but in the neutral or alkaline soils they are available in meagre quantities to green plants. The accumulation of calcium, sodium and magnesium salts in the soil results in alkalinity. The reaction of soil influences the absorption of water and soil solutes by roots through its direct effect on inhibition and permeability of root cell membranes.

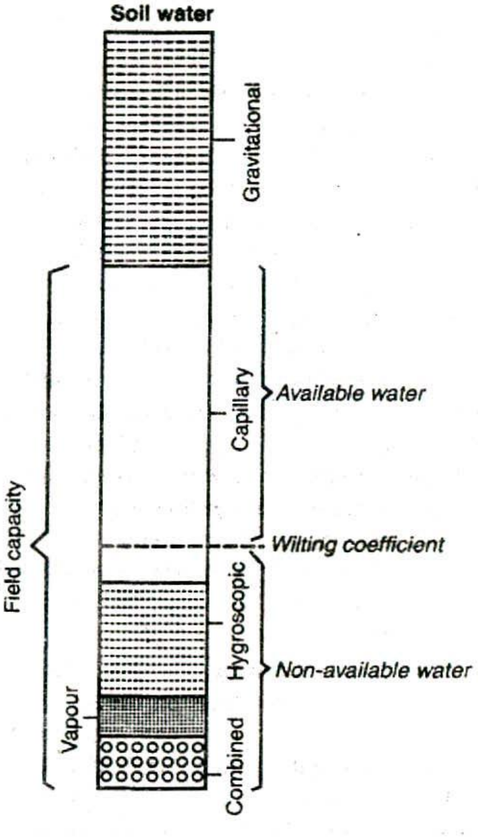

Fig. 2.12. Soil Water.

(*iii*) **Soil nutrients.** The nature and availability of soil solutes are fundamentally important from the standpoint of plant nutrition. Normally, inorganic solutes are absorbed by the plants in the ionic forms. Different species of plants, no doubt they require the same ions for their normal development, require them in varying quantities. In saline soil where the percentage of salt is high, only halophytes (salt loving plants) grow. Some plants require lime and grow in calcium rich soils. Such plants are called *calcicoles* or *calciphytes*. Some plants do not thrive well when they grow in calcium rich soil. They species are called *calcifuges* or *oxylophytes*.

Humus, a dark amorphous substance formed by partial degradation of dead organic remains is an important source of mineral and organic nutrients of plants. The fertility of soil is usually correlated with its humus content. Humus is the main source of nutrients for soil micro-organisms and green plants.

(*iv*) **Soil temperature.** Soil temperature in combination with other edaphic factors influences the properties of soil itself and plants as well. Low temperature reduces the rate of water and solute absorption by roots. Root injury due to low temperature in the winter is more common in sandy soil than in clay. Soil temperature is also important in the sense that it plays important role in determining the geographical distribution of plants on the earth. Soil temperature is affected by air temperature, the intensity of sunlight, the angles at which sun rays strike on the surface of soil, daily duration of sunlight, the amount of soil moisture and many other factors.

(*v*) **Soil atmosphere.** In the soil, the spaces left between soil particles are called pore spaces. These spaces contain air. Soil air contains slightly lower proportion of oxygen and higher one of CO_2 than atmospheric air contains. Water loged soil are deficient in oxygen. Normally, plenty of oxygen in the soil is necessary for the life of micro-organisms and other soil inhabitants. It is also necessary in the respiration of underground parts of higher plants. Oxygen content of the soil is also an important factor in seed germination. The germinating seeds respire rapidly and usually they require large amount of oxygen.

(*vi*) **Soil organisms.** The plants, animals and microbes inhabiting the soils show marked effects on the soil fertility. Decomposing agents, such as, bacteria, fungi, and many others convert dead organic matters into humus, free organic compounds and organic ions and thus make the nutrients available to plants. Some soil organisms secrete essential or beneficial substances including growth hormones and some of them secrete toxic substances in the soil which show marked effects on the growth and distribution of plants. Some of the bluegreen algae, like *Nostoc, Anabaena, Cylindrospermum* are beneficial to the higher plants because they fix atmospheric nitrogen into nitrogenous compounds that are utilised by the higher plants. Singh (1961) found that algal films that developed in paddy fields of Uttar Pradesh and Bihar were active nitrogen fixing bluegreen algae. The animals of burrowing habit also play important role in the soil by turning over the soil. Earthworms increase the fertility of the soil by adding excretory matters to it and also by making it loose. Local distribution of plant communities in different regions also brings about changes in the composition and fertility of the soil in those regions.

PHYSIOGRAPHIC FACTORS

Physiographic factors are those which are introduced by the structure, conformity and behaviour of the earth's surface, by topographic features such as elevation and slopes, by the geodynamic processes, such as silting and erosion and consequently by local geology. Mountain hills, valleys, etc. result from the irregularities in the earth's surface. These strong topographical reliefs tend to produce marked local climates or microclimates. The summits, for example, are different from the sides of mountains and narrow valleys are different from the open plains. At high altitude, the velocity of wind is high, temperature and air pressure decrease, humidity as well as intensity of light increases. Thus the climatic factors show variations and they become progressively extreme and rapid with increasing altitudes. Major topographic features influence the climate to a considerable extent, for example, the mountain ranges may cause heavy rainfall locally and low rainfall in their lees.

It has been observed that in the northern hemisphere north facing slopes tend to be more adjusted to moist conditions than the south facing ones at similar altitudes. This is so, probably, because of the effects of the solar radiations on the air and soil temperatures and consequently, on the relative humidity and evaporation and through them on the local water situation. The duration of sunlight on the south facing slope is longest. The vegetation on north facing slopes receives little or no direct solar radiations. The slope of the soil surface affects the vegetation directly as well as indirectly. The steepness of slope accelerates the circulation of soil water. The steeper the slopes the more rapid is downward movement of surface water. The water moving over the slopes causes erosion of the top soil and as a result of this vegetations disappear from the areas. Erosion and geodynamic agencies are active in mountain regions and about the sea coasts causing many types of changes in the topography. Such activities often cause formation of new open habitats, both at the sites of erosion and at the places where eroded soil is deposited. Moving sand dune in desert may be cited as example of geodynamic source of physiographic change. The areas subjected to quick and continuous erosion are completely devoid of vegetation.

BIOTIC FACTORS

The biotic factors include the influence of living organisms, both plants and animals upon the vegetation. Any activity of the living organism which may cause marked effects upon vegetation in any way is referred to as **biotic effect.** The biotic effect may be both direct and indirect. It may be beneficial to the plants in some respects but detrimental in other respects.

The plants live together in a community and influence one another. In the forest there are many plant communities, such as trees, shrubs, herbs, mosses, lichens. These communities interact with one another and adjust according to environmental conditions. Trees cast their shadow on many shade-loving plants which grow around or beneath them. The micro-organisms, such as bacteria, algae, fungi, and viruses affect the life of plants of a given area in many ways. Besides these, the decomposition of dead parts of plant bodies causes significant addition of organic compounds and humus to soil. In this way, vegetation modifies the habitat to a considerable extent. Similarly, animals which are in close association with plants also affect the plant life in one or several ways. Many animals use plants as their food and for shelter as well. Besides animals, the man is most significant agent for modifying the vegetation.

The biotic effects modifying the vegetation can be discussed in the following heads :

(1) Interactions between the plants and local animals and man.

(2) Interaction among plants growing in a community.

(3) Interaction between plants and soil micro-organisms.

1. Interaction between Plants and Local Animals and Man

These can be described under the following heads :

(*i*) Effects of grazing and browsing by animals.

(*ii*) Role of animals in the pollination.

(*iii*) Role of animals in the dispersal of seeds and fruits.

(*iv*) Insects and carnivorous plants.

(*v*) Effects of human activities on vegetation.

(*vi*) Myremecophily.

(*vii*) Miscellaneous effects.

(*i*) **Effects of grazing and browsing.** *Grazing* means eating away of unharvested herbs as forage by animals (Fig. 2.13), as for example, eating away of grasses by goats whereas *browsing* refers to a similar use of shrubs or trees by animals (Fig. 2.14), as for example, eating away of leaves and small twigs of *Margosa* (Neem) by camels. The animals destroy a large part of vegetation by grazing and browsing. Some animals prefer to graze and browse on some particular plant species, *i.e.*, they show selective grazing and browsing, *e.g.*, sheep normally prefer forbs, horses and cattle prefer grasses and goats and deer prefer woody and leafy parts of plants. Small annual plants become uprooted and disappear after being grazed. In browsing, taller plants such as trees and shrubs are little affected.

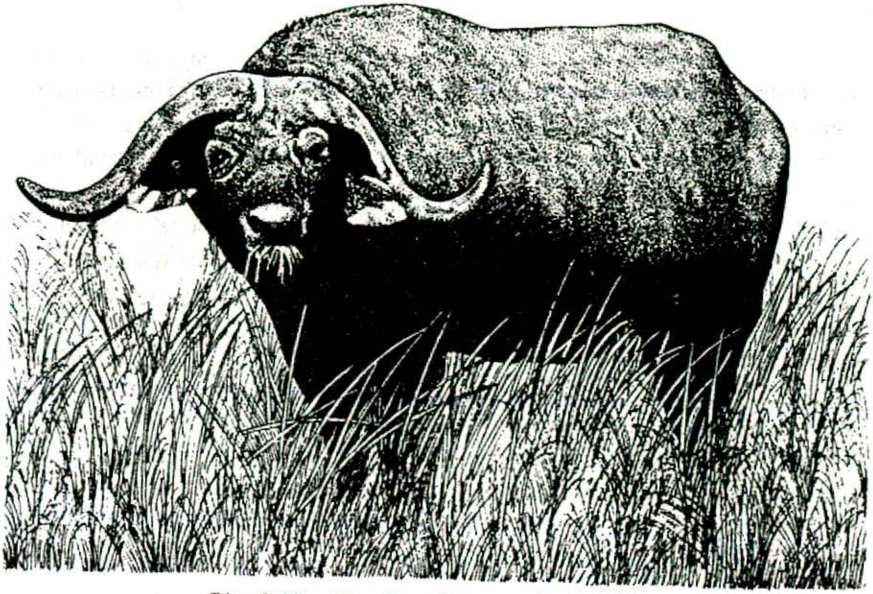

Fig. 2.13. Grazing of grasses by buffalo.

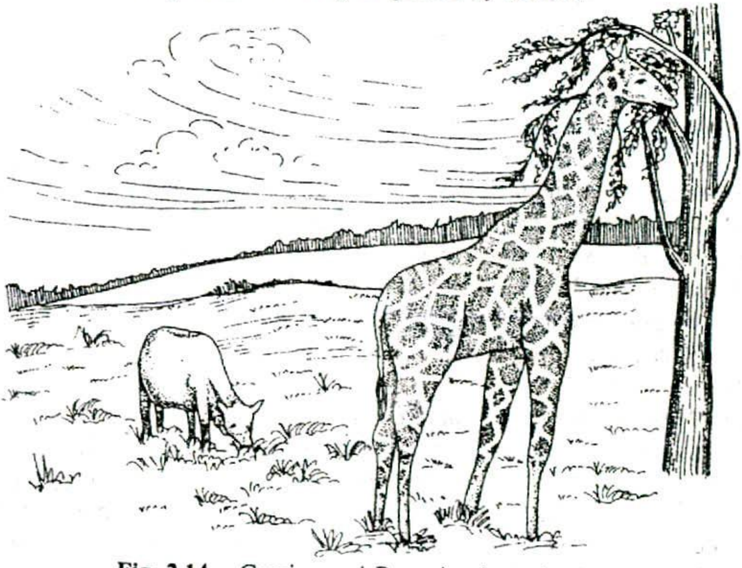

Fig. 2.14. Grazing and Browsing by animals.

Various other effects of grazing and browsing are summarised briefly in the following points :

(*a*) The grazing and browsing adversely affect the aeration of soil and make it compact and hard and finally render the soil unfit for the growth of trees and shrubs. Forests open to cattle are changed first into shrubby vegetations and finally into grasslands. Excessive grazing and browsing may thus change the pattern of vegetation and finally lead the area to develop into desert. Murphy (1951) is of the opinion that Sahara desert developed as a result of unchecked and excessive grazing by goats, sheep and by introduction of camels in the area. Experimental works near the periphery of Sahara by Kassas (1956) have shown that many vegetational changes took place when grazing by animals was completely checked. Unrestricted grazing and browsing are the main causes for the eastward spread of desert in the part of Punjab, Delhi and Rajasthan.

(*b*) The grazing and browsing reduce greatly the frequency of photosynthetic organs (leaves and apical green parts of stem) and thus curtail the assimilation.

(*c*) The grazing and browsing reduce the vegetation from the surface of earth to a considerable extent and thus expose the soil for erosion.

(*d*) The most important effect of grazing and browsing is the trampling. In the trampling complete destruction of small and weak annual herbs is caused by the hoofs, paws and feet of animals, but the shrubs and trees are little affected. Usually trampled area becomes inhabited by special type of plants which can withstand the mechanical effect of trampling. These plants propagate vegetatively and are not dependent upon the seed for their propagation. Some grasses, *Heylendia latibrosa,* for example, survive better in the grazed habitats than in non-grazed areas. Ecological differentiation due to grazing has been reported in certain other grasses and weeds. *Dichanthium annulatum* develops underground vegetative buds for reproduction in response to the grazing of above ground parts. Plants show certain protective measures such as bitter taste of leaves, stems and fruits, prickles and spines on the surfaces of stems and leaves, which keep the herbivores away from them.

(*e*) In grazed pasture and meadows, dung avoiding (coprophobic) plants disappear giving place for the colonization of non-coprophilous vegetation.

(*ii*) Role of animals in pollination. A large number of plants depend on insects, birds and a number of animals for their pollination. These plants develop coloured flowers. The flowers possess scents, nectar, sap, edible pollens and many other characteristic structures for attracting insects towards them. Insects, birds and other pollinators visit to the flowers in search of honey and edible pollens. Flowers in the families Rosaceae, Compositae, Leguminosae, Rutaceae, Umbelliferae, Euphorbiaceae, Cruciferae, Ranunculaceae are pollinated by insects. Some plants are specialized in their pollination by particular type of animals, for example, *Rafflesia* is pollinated by elephants and birds, bilipped flowers of *Salvia* are pollinated by bees, entomophilous flowers of orchids, *Ficus* and *Calotropis* are pollinated characteristically by insects. It is observed that different types of flowers and their pollinators generally live together in the same biotic communities and affect each other's life. R.F. Daubenmire says that "Extreme specialisation is as dangerous in connection with pollination as with other functions in the biological world, for not only must the ranges of two symbionts coincide but also the extinction of the one heralds the doom of the other."

Besides insects, birds, bats and some other animals, man too is taking active part in pollinating artificially one plant with the pollen of some other plant species. The artificial pollination is being used by man for the production of high yielding and disease resistant plant varieties.

(*iii*) **Role of animals in the dispersal of fruits and seeds.** Many animals, such as birds, bats, monkeys, act as important agents for disseminating the seeds, fruits and spores and thus they play important role in the migration of plants.

The seeds of many plants are very hard. Such seeds along with fleshy parts of fruits are swallowed by animals. While passing through the elementary canals of animals hard seeds are not affected by digestive juices.

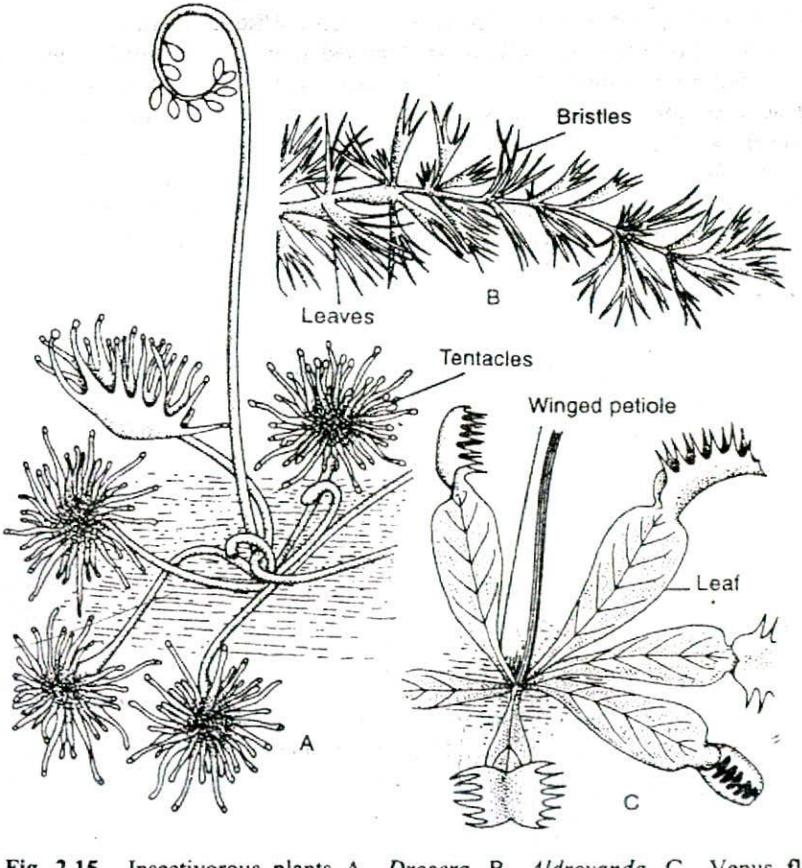

Fig. 2.15. Insectivorous plants A—*Drosera*, B—*Aldrovanda*, C—Venus fly trap (*Dionaea*)

When the animals leave faecal matter, the uninjured seeds present in it germinate. Passing of seeds through the digestive tracts sometimes facilitates their germination in certain cases. The seeds of tomato, tobacco, guava and many other plants are dispersed in this way.

The hairy, spiny, hooked and sticky fruits and seeds of some plants get entangled with the bodies of birds and other animals and with the clothes of man and are brought to distant places. When the animals clean their bodies at some places the seeds are dropped there. Seeds and fruits of *Xanthium, Andropogon, Plumbago, Aegle marmelos* are dispersed in the way.

Ants are good agents for transporting oily seeds and small grains of cereals.

(*iv*) Insects and Carnivorous plants. Semi-autotrophic insectivorous plants, as for example, pitcher plant, *Drosera* (Fig. 2.15A) *Aldrovanda* (Fig. 2.15B), *Dionaea* (Fig. 2.15C), bladderwort, etc., grow in the habitats which are deficient in nitrogenous compounds. These plants have some specialised organs and mechanisms for trapping and assimilating the preys.

Pitcher plants have leaf pitchers containing liquid and enzymes inside (Fig. 2.16). When the insects are trapped down in the pitcher they are digested and assimilated by it. In *Drosera* spathulate leaves are covered with sensitive glandular hairs which shine in the sunlight and attract insects and small flies. When the insects are entangled in the glandular hairs of leaves, digestive enzymes are secreted immediately which kill and digest the bodies of insects. The digested parts of insects are absorbed by the surface cells of the leaves.

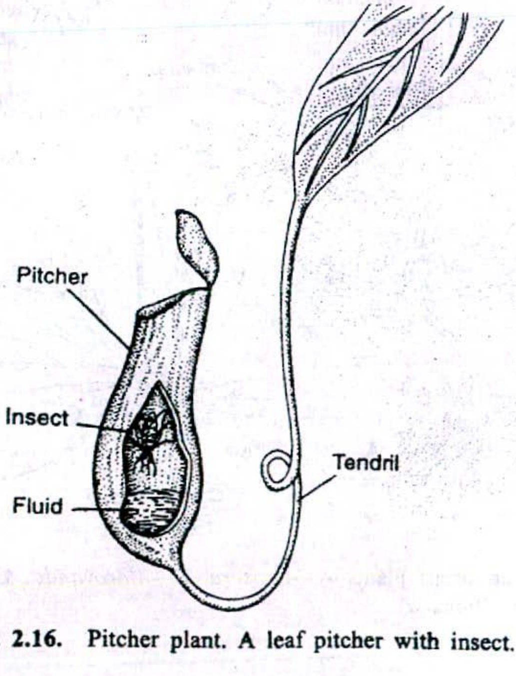

Fig. 2.16. Pitcher plant. A leaf pitcher with insect.

Utricularia (Bladderwort) is an aquatic insectivorous plant which is commonly found in ponds of India. Its bladders catch and digest small swimming aquatic animals (Fig. 2.17).

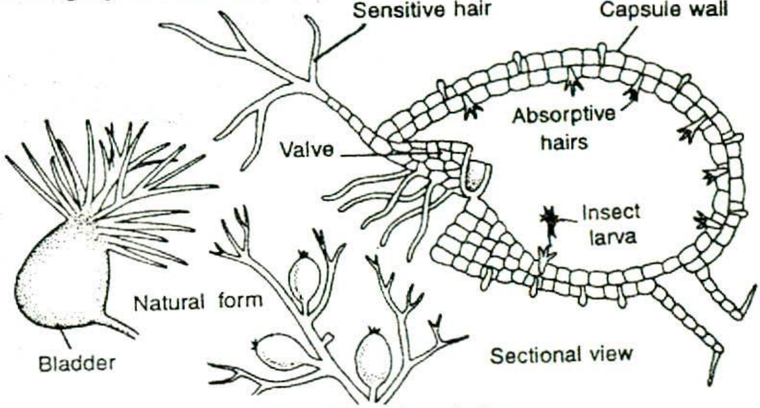

Fig. 2.17. *Utricularia.*

(*v*) **Effects of human activities on vegetation.** Man affects vegetation in the following ways :

(*a*) By cutting, felling and replanting the forest trees.

(*b*) **Cultivation.** Besides the old methods of cultivation, man has adopted a number of advanced methods for cultivation of plants. Cutting, budding, grafting and other methods used by man are proved beneficial for certain plants. Now at various research stations men are performing cross breeding experiments to evolve new varieties of plants that give high yields and are disease resistant. In cultivation, the destruction of weeds by man eliminates the competition among the plants. Proper spacing of plants during cultivation also checks the competition among them for food.

(*c*) **Fire.** Fire is a biological factor rather than a physical factor because it is mostly caused by man's activity. Lightning initiated fires have destroyed plants and animals since their early appearance on earth. In some countries, especially America and Africa, a lot of work has been done on the effects of fire on different ecosystems. A large body of information has developed on the effects of fire on glasslands and forests as well as on the use of fire in land management. The branch of ecology which deals with the effects of the fire on ecosystem is called "Fire ecology" or Ecopyrology. Plants having ability to withstand fire with little or no damage are referred to as *Pyrophytes.* A number of pyrophytes are known to occur in Siwalik hills. Important examples of pyrophytes are *Cochlospermum religiosa, Combretum nanum, Grewia sapida* etc. These small plants are supposed to have become permanently dwarf by annual jungle fires. Pyrophytes are mostly woody plants with thick bark.

Fires caused by man's activity are responsible for complete destruction of vegetation at certain places resulting in temporary or permanent alterations in the characters of vegetations. In some parts of tropics and subtropics, especially in Africa, the burning of grassland has been a regular practice for the last many centuries. Generally in fires the aerial parts of plants are destroyed completely but their roots, rhizomes or other underground parts may sometimes remain unaffected which under favourable conditions may grow and produce new plants. Fire generally makes the area suitable for the growth of grasses and thus improves the quality of forage. Post-burn plants are preferred by herbivores. Animals grazing on burnt grasslands are found to gain in weight more rapidly than those grazing on unburnt grasslands. Fire removes harmful plant and animal parasites and pests.

Litter accumulations physically prevent the healthy production and growth of some plant species in grassland. Fire not only removes the choking litter accumulation but also reduces the organic debris to ash. It affects the productivity by stimulating both the above and below ground growth, increases flowering in forbs and seed production in grasses, increases certain species like legumes and improves nutrient contents of the grassland species. Burning in normal course does not affect the grassland soils adversely and generally improves them. Mineral salts of calcium, magnesium, potassium and phosphorus increase with burning. Excessive burning may reduce the humus content and the fertility of the soil. Soil acidity increases and erosion is accelerated. Annual burning coupled with continuous heavy-grazing will have detrimental effects on the health of grassland. The grazing-burning rotation is very useful in the management of Pampas or Savannahs. In the ancient times man used fires to clean forest vegetations and also for lightening purposes. Vansteen (1936) is of the opinion that many deserts in the old world are man-made. Recent works in Australia by Spech *et al.* (1958), Coaldrabe (1951) and in Canada by Schmidt (1960) have thrown light on the significance of fire in determining the type and composition of plant communities.

(*d*) Man also clears the vegetation for making houses, roads, etc.

(*e*) In ancient times many human invasions took place in India which caused great destruction of vegetation. Alexander (330 B.C.), Muslim invasion after 850 A.D. Gori and Gaznavi, and Rajput invasions destroyed dense forests and converted them into deserts. Mohanjodaro and Harappa are examples which are supposed to have become deserted as a result of human invasions. The excavations of Mohanjodaro and Harappa indicate that shrubby plants were abundant in the desert areas of Punjab and Sindh.

(*vi*) **Myremecophily.** Sometimes ants take their abode or shelter on some trees such as Mango, Litchi, Jamun, South American *Acacia* (*Acacia sphaerocephala*) (Fig. 2.18) and so on. These ants act as body guards of the plants against any disturbing agent. In lieu of this defence, the plants provide food and shelter to these ants. This phenomenon is known as myremecophily.

(*vii*) **Miscellaneous effects.** The animals also affect the plant life in many other ways. Some animals, as for example, barkeater, rodents may kill a large number of trees. Juice sucking insects, woodpeckers, bud eating birds, sparrow, squirrel and other animals cause great harm to the vegetation. Elephants detach the branches of the trees and sometimes uproot the gigantic trees.

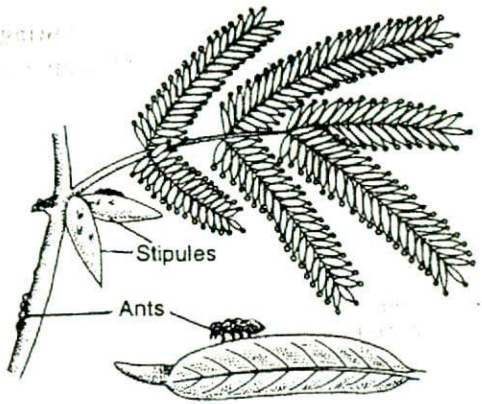

Fig. 2.18. Myremecophily

The insects, birds, squirrels, mice and rodents eat abundant seeds. Some animals eat and destroy seeds at the sowing time. Fishes, ducks and other aquatic animals depend upon aquatic plants for food and shelter.

Termites are chief agents for destroying seeds, seedlings and standing crop plants in the fields. Termites and their termitaria serve important ecological function in African Tropical wet-dry soils which has been appreciated and utilized by indigenous African agriculturists in northern Malawi and neighbouring south-western Tanzania. Howard W. Mielke (Tropical Ecology. Vol. 19, No. 1, 1978) has highlighted the importance of termites and termitaria in Tropical wet dry Africa. Termites and termitaria contribute to the development of soils. The enhancement of the mineral content in termite mounds as compared to adjacent soils has been observed by many workers (Hesse, 1955; Stoops, 1964; Lee and Wood, 1971; Watson, 1 75; Milne, 1974; Waston, 1969; Bouillon, 1970). This enhancement in mineral contents of termite mounds has been attributed to the interaction of several factors.

(1) Termite behaviour in aggregating finer soil particles within their mounds; (2) termite behaviour in collecting and storing significant amount of plant matter and accompanying base minerals in their mounds, and (3) relatively low rate of leaching occurring on the mounds due to their dome shape and concomitant propensity to shed water. Nitrogen fixing bacteria have been found associated with some species of termites and as a result of this association some species of termites facilitate the fixation of significant amounts of nitrogen. Termites are important food in the human diet of Africans of the Tropical dry-wet climatic regime. Termitaria soils are used as a raw material for the production of cement, mortar, plaster and bricks and are used in the construction of everything from buildings to roads (Lee

and Wood, 1971). Termites and shifting cultivation also provide nutrients and habitats for migratory Palaearctic birds.

2. Interaction Among Plants Growing in a Community

Various plants in a community react with one another in several ways for :

(*i*) Water,

(*ii*) Essential minerals and organic compounds, and

(*iii*) Light and air.

The taller plants modify the habitat for the plants growing around and underneath them by casting shadow, protecting them from injuries by strong wind, by increasing the atmospheric humidity, and by determining the humus content of the soil.

The most interesting instances of interactions among plants growing in a community are as follows :

(*i*) Action of lianas;

(*ii*) Effects of some epiphytes;

(*iii*) Effects of parasitic plants.

(*i*) **Action of lianas.** Lianas are woody vascular plants growing on the ground, maintaining, more of less, autotrophic mode of life and growing upward taking support of some trees and other objects. The woody stems of these plants have well developed alternating vertical columns of secondary xylem and parenchymatous tissues which enable them to twist around the supporting objects (Fig. 2.19). In tropical evergreen forests, lianas grow at the top of the trees and form the top layer of the forest canopy. This habit enables these lianas to get sufficient light. The lianas affect other plants also because they cast their shadow and check the light from reaching to the plants of lower storeys.

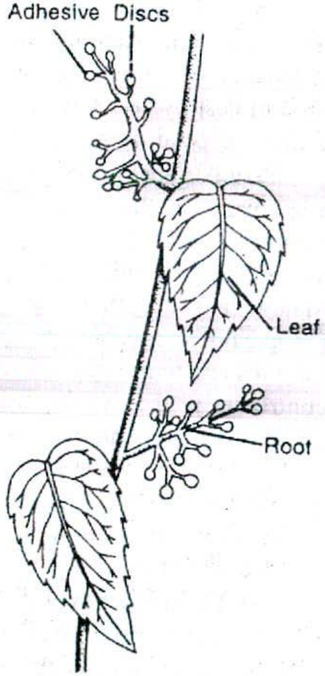

Fig. 2.19. A liana.

(*ii*) **Effects of some epiphytes.** The epiphytes grow on the leaves and stems of other plants. They are autotrophic and are dependent on other plants only for support. Epiphytes differ from parasites in not taking food from the hosts and also differ from lianas in not having any permanent connection with the soil. The examples of epiphytes may be found in the families Orchidaceae, Asclepiadaceae, Bromeliacease. Cactaceae, etc.

Dischidia, Tillandsia are most common examples. Epiphytes are found in humid climates. The two main problems for these plants are (*a*) maximum absorption of water from the atmosphere and from the bark surface of the supporting plant and (*b*) maximum economy in the water consumption. These plants develop two types of roots, namely the aerial and clinging roots. The aerial roots are thick and have special thin walled porous absorptive tissue, the 'velamen' on their surface. These roots absorb rain water and moisture from the atmosphere. The clinging roots fix the epiphytes on the surface of supporting plants. Because the epiphytes are autotrophic. they do not affect the supporting plants to any considerable extent.

(*iii*) **Effects of parasitic plants.** Some plants are heterotrophic and are dependent on other plants for their food requirements. They are called parasites. These are of the following two types :

(*i*) Ectoparasites (external parasite); and

(*ii*) Endoparasites (internal parasites).

The endoparasites are more destructive than the ectoparasites. Because the parasites take their food from host plants, they check the growth and ultimately cause the death of their hosts. *Cuscuta, Loranthus, Orobanche, Rafflesia,* and sandal wood tree (*Santalum album*) are important parasitic angiosperms which may grow either on roots or on stems and some time even on the leaves of the higher plants. The parasites may be either obligate or facultative.

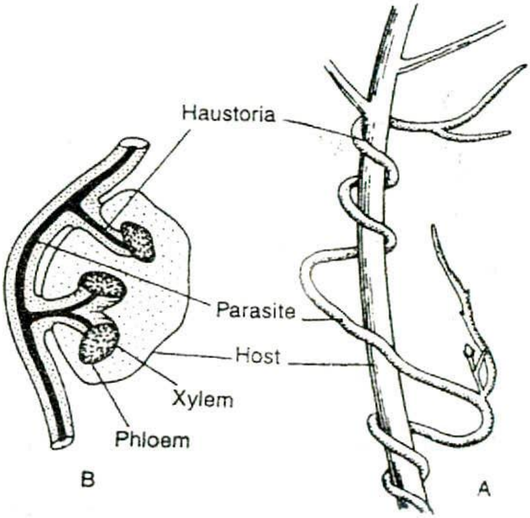

Fig. 2.20. A—*Cuscuta* on the host. B—T.S. of host along with *Cuscuta.*

Cuscuta (Fig. 2.20 A & B) is an obligate stem parasite on *Acacia, Zizyphus* and a number of other angiospermic plants. *Loranthus* is a partial stem parasite on mango. *Orobanche* grows very commonly on the roots of crucifers and solanaceous plants as obligate roots parasite. Other important parasites are *Rafflesia* on the roots of *Vitis Viscum album* on coniferous trees. *Striga,* one of the smallest angiospermic parasites grows on the grasses, *Arceuthobium minutissimum,* and interesting smallest parasitic dicot, is an obligate stem parasite of *Pinus excelsa.*

Besides angiospermic parasites, fungi and bacteria are also known to parasitise plants and cause several destructive diseases in them.

Puccinia graminis is a parasitic fungus causing rust diseases in wheat. Mildews, smuts,, white rust, damping off, and blight diseases are generally caused by parasitic fungi.

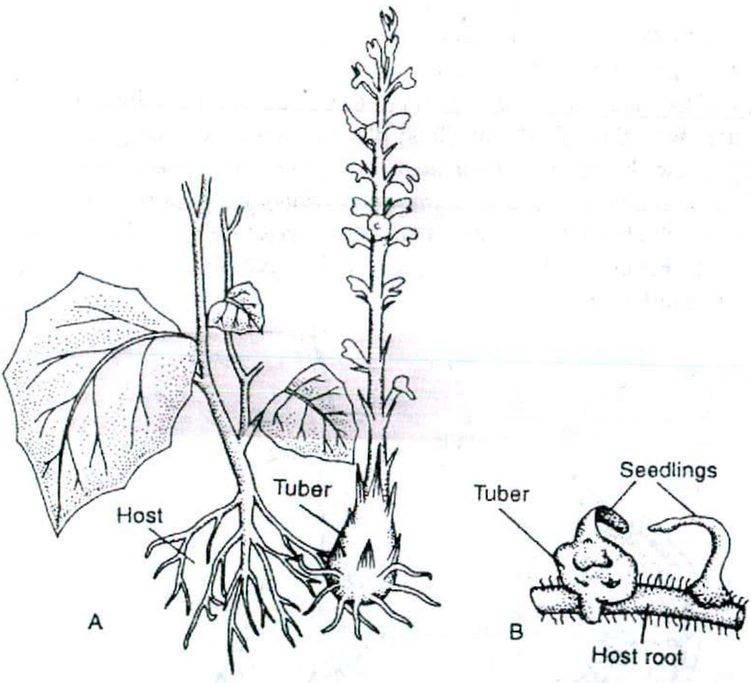

Fig. 2.21. A & B-*Orobanche*. A—Parasite growing on the root of brinjal. B—A root of host with growing seedlings of parasite.

Some algae are also known to parasitise several plants and cause diseases in them. Most common example is *Cephaleuros* which is found on a number of angiosperms.

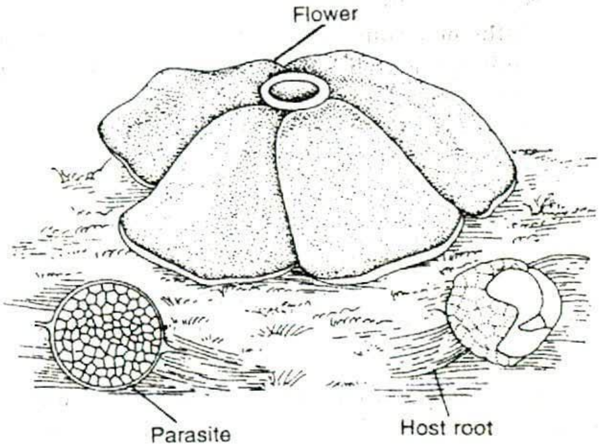

Fig. 2.22. *Rafflesia* on the root of *Vitis.*

3. Interaction between Plants and Micro-organisms

Various kinds of bacteria, protozoa, algae, fungi, worms, nematodes and other soil microbes act as important agents which alter the physical and chemical properties of the soils, and increase or decrease their fertility. These changes in the soil properties have great impact on the nature and growth of vegetation. Very often soil microbes, such as nematodes, bacteria and fungi cause many diseases in the underground parts of plants. Viruses too cause several mosaic and other diseases in many plants, as for example, the curling of tomato leaves, mosaic patterns in papaya and lady's finger (bhindi), bean mosaic, tobacco mosaic, etc.

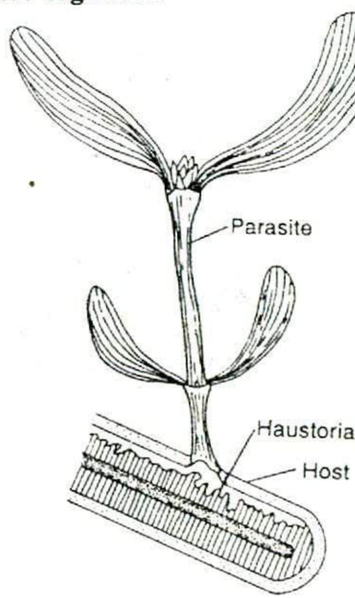

Fig. 2.23. Mistletoe (*Viscum*), a partial stem parasite.

Some microbes secrete growth stimulating substances in the soil which induce the growth of plants.

Besides above effects, the soil micro-organisms show symbiotic activities and many soil fungi form mycorrhizal association with the roots of higher plants. These two phenomena, *i.e.*, symbiosis and mycorrhizal associations are described below.

Symbiotic influence. Some soil microbes live in close association with plants, both benefiting each other. In this association both the organisms are interdependent and they do not harm each other. This mutual relationship between two organisms is known as symbiosis and the interdependent organisms are called symbionts.

Many cases of symbiosis in plants are known. The nodulated roots of legumes contain nitrifying bacteria (*Rhizobium*) (Fig. 2.24). These bacteria fix atmospheric nitrogen into nitrogenous compounds and benefit the legumes by supplying nitrogenous compounds in usable form. The leguminous plants, in return, provide nutrients, water and shelter to bacteria. When the roots of these plants die, decomposition of dead remains takes place in which the nitrogenous substances; nitrite, nitrate and ammonium ions are absorbed by the plants. *Nostoc* and *Anabaena* living symbiotically in the coralloid roots of *Cycas* also fix atmospheric nitrogen.

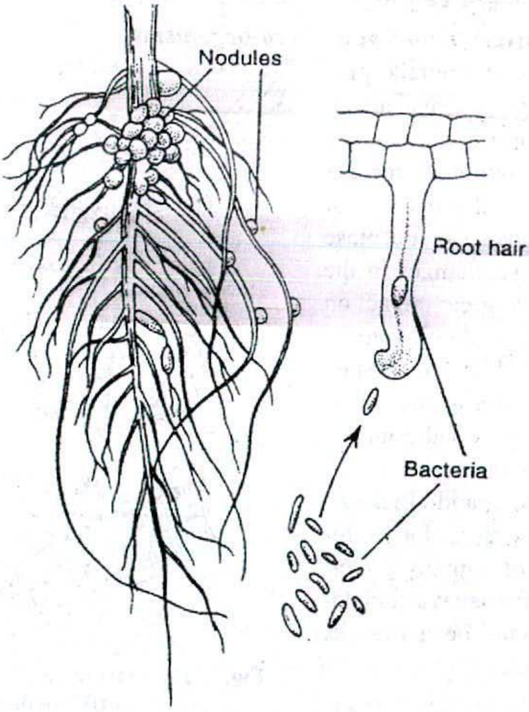

Fig. 2.24. A nodulated root, soil bacteria and infected root hair.

Lichens also show symbiosis. These are synthetic plants in which algae and fungi live symbiotically. Generally, the algal component belongs to myxophyceae and fungal components are ascomycetous or sometimes basidiomycetous forms. In this association, algal component fixes the atmospheric nitrogen, prepares food and supplies nutrients to its fungal counterpart. Fungal component gives support to the algal component. It also saves algae from desiccation because of its sponginess and high water holding capacity.

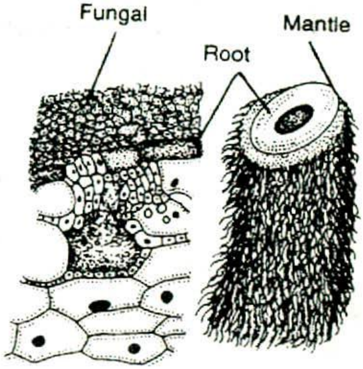

Fig. 2.25. Ectotrophic mycorrhiza or the root fungus

Mycorrhizal association. Sometimes fungi grow on the surface or inside the roots of higher plants. They are called mycorrhizae. Micorrhizae are of two types.

(*i*) *Ectotrophic mycorrhiza*. Fungus lives on the surface of roots of higher plants (Fig. 2.25).

(*ii*) *Endotrophic mycorrhiza*. Fungus penetrates the deeper tissues of the roots and rhizomes (Fig. 2.26).

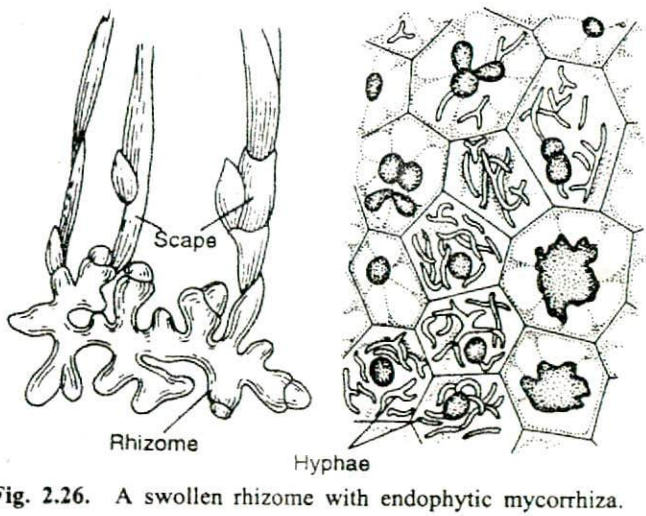

Fig. 2.26. A swollen rhizome with endophytic mycorrhiza.

The roots with mycorrhizae are unbranched and without root-caps and root hairs. Fungal hyphae in this association act like root hairs, absorb water and minerals from the soil and supply them to the roots. The roots in return, provide food and shelter to the mycorrhizae. It has been estimated that some species of plants in about 80% families of seed plants have mycorrhizal association. Blue berries cannot grow without mycorrhiza. Orchid seedlings do not develop properly unless they become infected with mycorrhizae.

Recent researches have shown that mycorrhizae play very important role in the root tissues. They regulate acidity and sugar content in the root tissues and enable the roots grow vigorously.

QUESTIONS

1. What is environment? What are various environmental factors which influence the plant life?
2. What are the effects of light on vegetation? What is the significance of light to plants?
3. What are the effects of biological factors on plants?
4. Write short notes on :
   Biotic factors, Mycorrhiza, Soil profile, Soil water, Effect of wind on vegetation.

3

ECOSYSTEM

An organism is always in the state of perfect balance with the environment. The environment literally means the surroundings. The environment refers to the things and conditions around the organisms which directly or indirectly influence the life and development of the organisms and their populations. Organisms and environment are two non-separable factors. Organisms interact with each other and also with the physical conditions that are present in their habitats. "The organisms and the physical features of the habitat form an ecological complex or more briefly an ecosystem." (Clarke, 1954).

The concept of ecosystem was first put forth by A.G. Tansley (1935). Ecosystem is the major ecological unit. It has both structure and functions. The structure is related to species diversity. The more complex is the structure the greater is the diversity of the species in the ecosystem. The functions of ecosystem are related to the flow of energy and cycling of materials through structural components of the ecosystem.

According to Woodbury (1954), ecosystem is a complex in which habitat, plants and animals are considered as one interesting unit, the materials and energy of one passing in and out of the others.

According to E.P. Odum, the ecosystem is the basic functional unit of organisms and their environment interacting with each other and with their own components. An ecosystem may be conceived and studied in the habitats of various sizes, *e.g.*, one square metre of grassland, a pool, a large lake, a large tract of forest, balanced aquarium, a certain area of river and ocean. All the ecosystems of the earth are connected to one another, *e.g.*, river ecosystem is connected with the ecosystem of ocean, and a small ecosystem of dead logs is a part of large ecosystem of a forest. A complete self-sufficient ecosystem is rarely found in nature but situations approaching self-sufficiency may occur.

Structure of Ecosystem

The structure of an ecosystem is basically a description of the organisms and physical features of environment including the amount and distribution of nutrients in a particular habitat. It also provides information regarding the range of climatic conditions prevailing in the area. From the structure point of view, all ecosystems consist of the following basic components :

1. Abiotic components
2. Biotic components

Abiotic Components

Ecological relationships are manifested in physico-chemical environment. Abiotic component of ecosystem includes basic inorganic elements and compounds, such as soil, water, oxygen, calcium carbonates, phosphates and a variety of organic compounds (by-products of organic activities or death). It also includes such physical factors and ingredients as moisture, wind currents and solar radiation. Radiant energy of sun is the only significant energy source for any ecosystem. The amount of non-living components, such as carbon, phosphorus, nitrogen, etc. that are present at any given time is known as standing state or standing quantity.

Biotic Components

The biotic components include all living organisms present in the environmental system. From nutrition point of view, the biotic components can be grouped into two basic components :

(*i*) Autotrophic components, and

(*ii*) Heterotrophic components

The autotrophic components include all green plants which fix the radiant energy of sun and manufacture food from inorganic substances. The heterotrophic components include non-green plants and all animals which take food from autotrophs. So biotic components of an ecosystem can be described under the following three heads :

1. Producers (Autotrophic components),
2. Consumers, and
3. Decomposers or reducers and transformers

The amount of biomass at any time in an ecosystem is known as standing crop which is usually expressed as fresh weight, dry weight or as free energy in terms of calories/metre^2.

Producers (Autotrophic elements). The producers are the autotrophic elements—chiefly green plants. They use radiant energy of sun in photosynthetic process whereby carbon dioxide is assimilated and the light energy is converted into chemical energy. The chemical energy is actually locked up in the energy rich carbon compounds. Oxygen is evolved as by-product in the photosynthesis. This is used in respiration by all living things. Algae and other hydrophytes of a pond, grasses of the field, trees of the forests are examples of producers. Chemosynthetic bacteria and carotenoid bearing purple bacteria that also assimilate CO_2 with the energy of sunlight but only in the presence of organic compounds also belong to this category.

The term producer is misleading one because in an energy context, producers produce carbohydrate and not energy. Since they convert or transduce the radiant energy into chemical form, E.J. Kormondy suggests better alternative terms *'converters'* or *'transducers'*. Because of wide use the term producer is still retained.

Consumers. Those living members of ecosystem which consume the food synthesized by producers are called consumers. Under this category are included all kinds of animals that are found in an ecosystem. There are different classes or categories of consumers, such as,

(*a*) Consumers of the first order or primary consumers,

(*b*) Consumers of the second order or secondary consumers,

(*c*) Consumers of the third order or tertiary consumers, and

(*d*) Parasites, scavengers and saprobes.

(*a*) ***Primary consumers.*** These are purely herbivorous animals that are dependent for their food on producers or green plants. Insects, rodents, rabbit, deer, cow, buffalo, goat are some of the common herbivores in the terrestrial ecosystem, and small crustaceans, molluscs, etc. in the aquatic habitat. Elton (1939) named herbivores of ecosystem as "key industry animals". The herbivores serve as the chief food source for carnivores.

(*b*) ***Secondary consumers.*** These are carnivores and omnivores. Carnivores are flesh eating animals and the omnivores are the animals that are adapted to consume herbivores as well as plants as their food. Examples of secondary consumers are sparrow, crow, fox, wolves, dogs, cats, snakes, etc.

(*c*) ***Tertiary consumers.*** These are the top carnivores which prey upon other carnivores, omnivores and herbivores. Lions, tigers, hawk, vulture, etc. are considered as tertiary or top consumers.

(*d*) Besides different classes of consumers, the **parasites, scavengers** and **saprobes** are also included in the consumers. The parasitic plants and animals utilize the living tissues of different plants and animals. The scavengers and saprobes utilize dead remains of animals and plants as their food.

Decomposers and transformers. Decomposers and transformers are the living components of the ecosystem and they are fungi and bacteria. Decomposers attack the dead remains of producers and consumers and degrade the complex organic substances into simpler compounds. The simple organic matters are then attacked by another kind of bacteria, the *transformers* which change these organic compounds into the inorganic forms that are suitable for reuse by producers or green plants. The decomposers and transformers play very important role in maintaining the dynamic nature of ecosystems.

Function of Ecosystem

An ecosystem is a discrete structural, functional and life sustaining environmental system. The environmental system consists of biotic and abiotic components in a habitat. Biotic component of the ecosystem includes the living organisms; plants, animals and microbes whereas the abiotic component includes inorganic matter and energy. Abiotic components provide the matrix for the synthesis and perpetuation of organic components (protoplasm). The synthesis and perpetuation processes involve energy

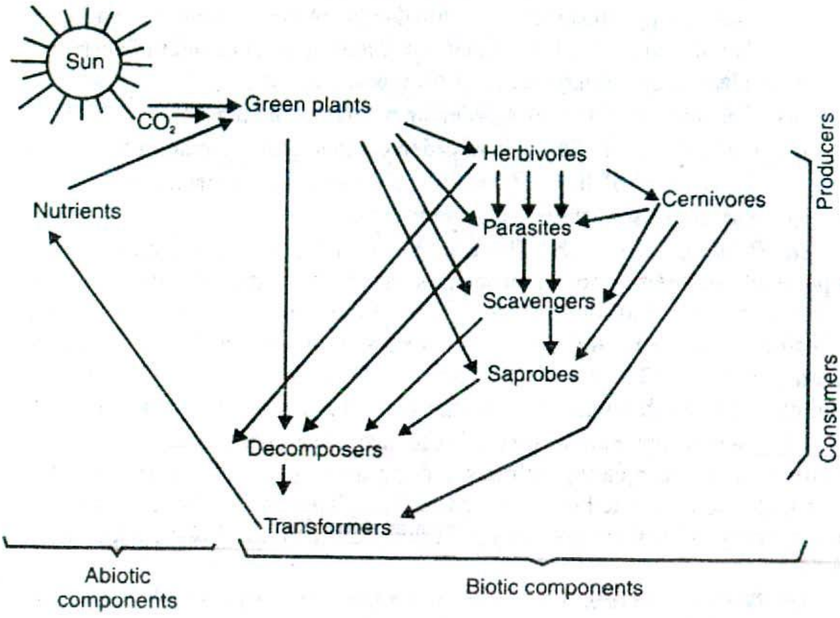

Fig. 3.1. Different components of ecosystem.

exchange and this energy comes from the sun in the form of light or solar energy. Thus, in any ecosystem we have the following functional components :

(*i*) inorganic constituents (air, water and mineral salts)

(*ii*) organisms (plants, animals and microbes), and

(*iii*) energy input which enters from outside (the sun)

These three interact and form an environmental system. Inorganic constituents are synthesized into organic structures by the green plants (primary producers) through photosynthesis and solar energy is utilized in the process. Green plants become the source of energy for renewals (herbivores) which, in turn become source of energy for the flesh eating animals (carnivores). Animals of all types grow and add organic matter to their body weight and their source of energy is complex organic compound taken as food. They are known as secondary producers. All the living organisms whether plants or animals in an ecosystem have a definite life span after which they die. The dead organic remains of plants and animals provide food for saprophytic microbes, such as bacteria, fungi and many other animals. The saprobes ultimately decompose the organic structure and break the complex molecules and liberate the inorganic components into their environment. These organisms are known as decomposers. During the process of decomposition of organic molecules, the energy which kept the inorganic components bound together in the form of organic molecules gets liberated and dissipated into the environment as heat energy. Thus in an ecosystem energy from the sun, the input is fixed by plants and transferred to animal components. Nutrients are withdrawn from the substrate, deposited in the tissues of the plants and animals, cycled from one feeding group to another, released by decomposition to the soil, water and air and then recycled. The ecosystems operating in different habitats, such as deserts, forests, grasslands and seas are interdependent of one another. The energy and nutrients of one ecosystem may find their way into another so that ultimately all parts of the earth are interrelated, each comprising a part of the total system that keeps the biosphere functioning.

Thus the principal steps in the operation of ecosystem are as follows :

(1) reception of radiant energy of sun,

(2) manufacture of organic materials from inorganic ones by producers,

(3) consumption of producers by consumers and further elaboration of consumed materials; and.

(4) after the death of producers and consumers, complex organic compounds are degraded and finally converted by decomposers and converters into such forms as are suitable for reutilization by producers.

The principal steps in the operation of ecosystem not only involve the production, growth and death of living components but also influence the abiotic aspects of habitat.

It is now clear that there is transfer of both energy and nutrients from producers to consumers and finally to decomposers and transformers levels. In this transfer there is a progressive decrease of energy but nutrient component is not diminished and it shows cycling from abiotic to biotic and *vice versa*.

The flow of energy is unidirectional. The two ecological processes—energy flow and mineral cycling which involve interaction between biotic and abiotic components lie at the heart of ecosystem dynamics. The principal steps and components of ecosystem are illustrated in Fig. 3.1.

MAJOR ECOSYSTEMS (BIOMES)

According to Whittaker, R.H. (1970), the major community conceived in terms of physiognomy on a given continent is a *biome* or *formation*. 'Biome' is used when the concern is with both plants and animals and '**formation**' is used when the concern is with plant communities only. These are the products of interaction of regional climate with biota and substrate. A biome is a grouping of terrestrial ecosystems on a given continent that are similar in vegetation structure (physiognomy), in the major features of environment to which this structure is a response and in some characteristics of their animal communities. The biome concept which is most widely applied to land ecosystems can also be applied in aquatic environment to such zones as the worldwide structural types defined by major kinds of organisms.

In the broadest sense, there are two major types of ecosystems namely terrestrial and aquatic.

Terrestrial ecosystem operates on the land while the aquatic system operates in the aquatic habitat (Fig. 3.2).

Terrestrial ecosystem can further be divided into the following types :

(1) Forest ecosystem

(2) Grassland ecosystem

(3) Desert ecosystem

(4) Artificial ecosystems which are man-made, as for example, crop fields and gardens.

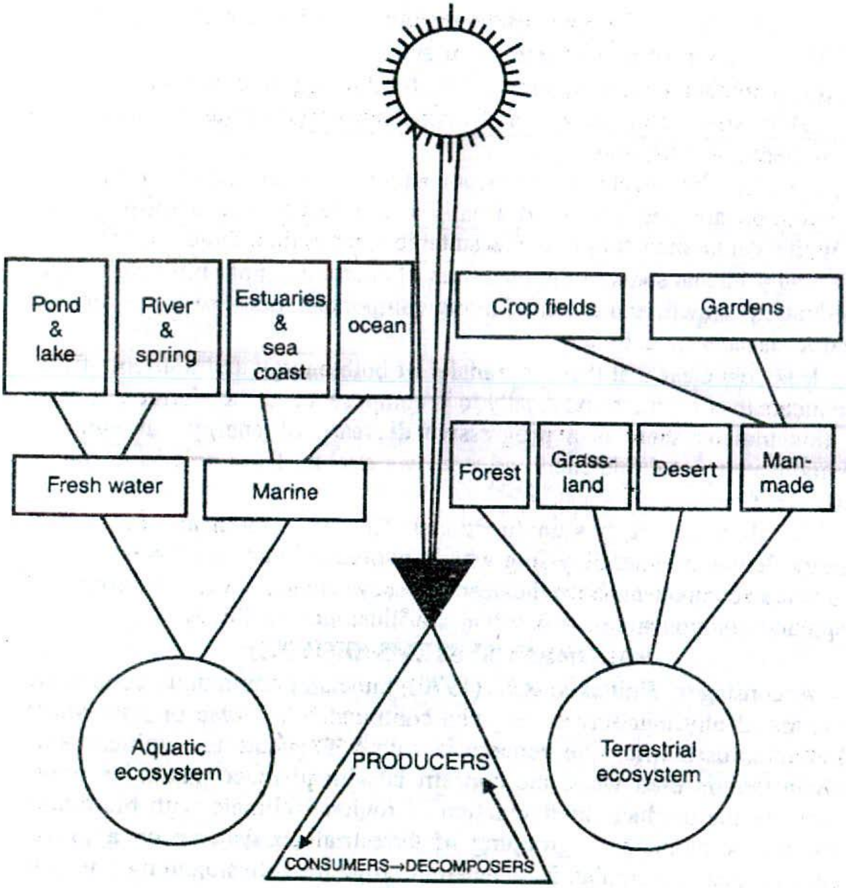

Fig. 3.2. Different types of ecosystems.

On the basis of salt contents in water, aquatic ecosystems can be divided into the following two types of minor ecosystems :

(1) Fresh water ecosystems

(2) Marine or oceanic ecosystems

The fresh water ecosystems include pond ecosystem, lake ecosystem, river ecosystem and spring ecosystem.

SOME EXAMPLES OF ECOSYSTEMS

Pond and Lake as Ecosystems

Pond and lake are fresh water ecosystems in which, like other ecosystems, there are two main components :

(*A*) Abiotic component

(*B*) Biotic component

(A) Abiotic component. Abiotic component of pond consists of water, dissolved minerals, oxygen and carbon dioxide. Solar radiations are the main source of energy.

(B) Biotic component. It includes the following :

(*i*) Producers

(*ii*) Consumers

(*iii*) Decomposers and transformers.

On the basis of water depth and types of vegetation and animals there may be three zones in a lake or pond : *littoral, limnetic* and *profundal.* The littoral zone is the shallow water region which is usually occupied by rooted plants. The limnetic-zone ranges from the shallow to the depth of effective light penetration and associated organisms are small crustaceans, rotifers, insects, and their larvae and algae. The profundal zone is the deep

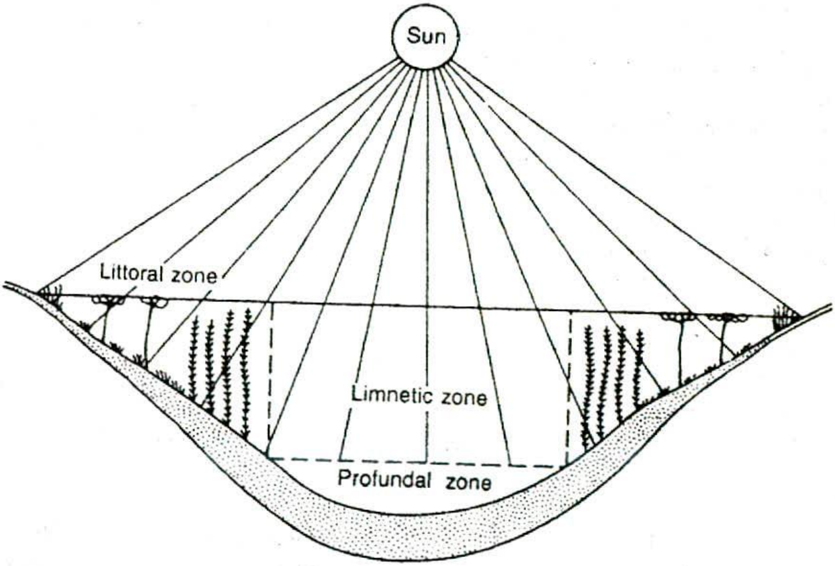

Fig. 3.3 Different zones of a fresh water pond.

water parts where there is no effective light penetration. The associated organisms are snails, mussels, crabs and worms (Fig. 3.3).

(*i*) **Producers.** The main producers in pond or lake ecosystem are algae and other aquatic plants, such as *Azolla, Hydrilla, Potamogeton, Pistia, Wolffia, Lemna, Eichhornia, Nymphaea, Jussiaea,* etc. These are either floating or suspended or rooted at the bottom. The green plants convert the radiant energy into chemical energy through photosynthesis. The chemical energy stored in the form of food is utilised by all the organisms. Oxygen evolved by producers in photosynthesis is utilised by all the living organisms in respiration.

(*ii*) **Consumers.** In a pond ecosystem, the primary consumers are tadpole larvae of frogs, fishes and other aquatic animals which consume green plants and algae as their food. These herbivorous aquatic animals are the food of secondary consumers. Frogs, big fishes, water snakes, crabs are secondary consumers. In the pond, besides the secondary consumers, there are consumers of highest order, such as water-birds, turtils, etc.

(*iii*) **Decomposers and Transformers.** When aquatic plants and animals die, large number of bacteria and fungi attack their dead bodies and convert the complex organic substances into simpler inorganic compounds and elements. These micro-organisms are called *decomposers*. The chemical elements liberated by decomposers are again utilized by green plants in their nutrition (Fig. 3.4).

Ocean as an Ecosystem

The oceans constitute nearly 70 per cent of the earth's surface. The sea has unusual stability in temperature, salinity and gaseous content. The upper portion of the oceanic region through which light penetrates is called euphotic zone. The region of the ocean below the euphotic zone (below 200 metres) is called *benthal*. It is also known as aphotic zone. This zone is completely free of photosynthetic organisms. Thus, different sets of environmental conditions are present in different zones of the ocean and each zone has its own peculiar life form. Planktonic organisms are algae, diatoms, protozoa, small crustaceans and their eggs. The seashore organisms live under variable physical conditions and they are constantly under the impact of waves. Most of them are covered and exposed twice daily by the rise and fall of the tides.

Streams and Rivers

In the rivers and streams or in the shallow water, the velocity of current is fast to keep the bottom clear. Filamentous algae and fishes are common examples of producers and consumers respectively. In the zone of deep water the velocity of water current is reduced and silt and other loose materials tend to settle at the bottom.

Wet Lands

These are marshes and swamps which are low lying wet lands and their ecosystems are suitable for ducks and other semi-aquatic animals. Swamps also support large trees and shrubs. They have various types of environmental conditions, both aquatic and semi-aquatic. Aquatic insects, reptiles and birds are common in such regions.

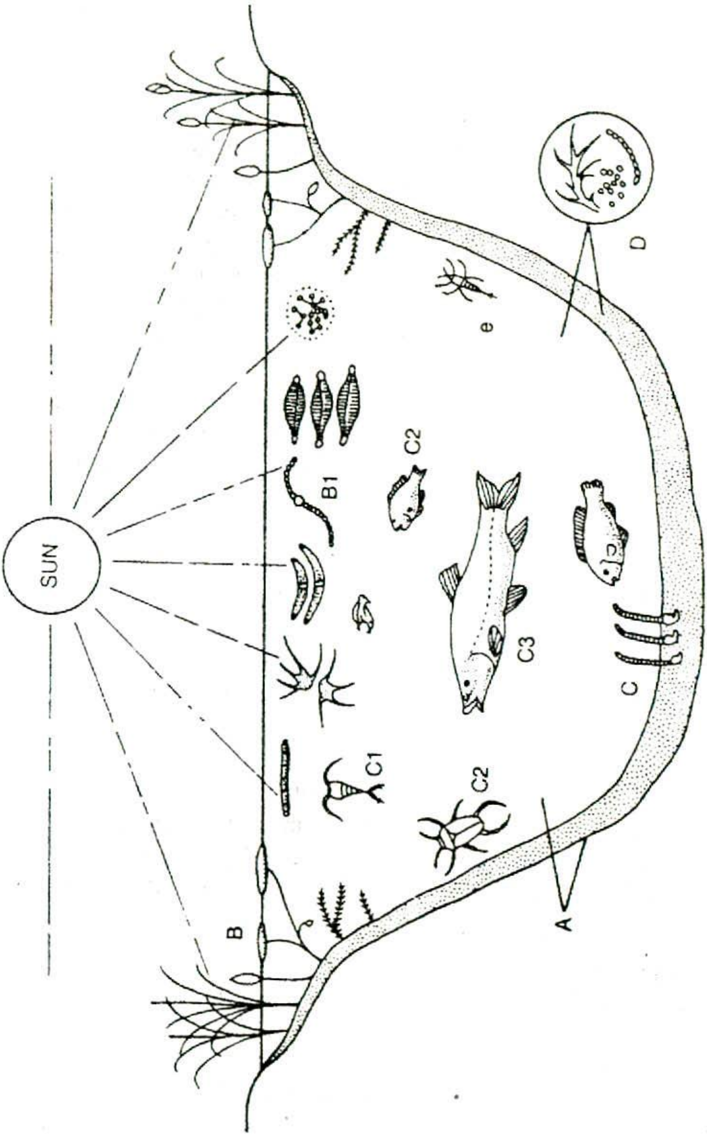

Fig. 3.4 A pond ecosystem.
A—Abiotic component; B and B1—Producers; C1—Primary consumers (herbivoers); C2—Secondary consumers; C3—Tertiary consumers; D—Decomposers—saprophytic bacteria and fungi.

Forest as an Ecosystem

Forest ecosystem is the best example of a terrestrial ecosystem. Like other ecosystems, there are two main components of forest ecosystem :

(*A*) Abiotic component

(*B*) Biotic component.

(A) Abiotic component. In a forest ecosystem soil, moisture, air and sunlight form the abiotic or physical component.

(B) Biotic component. There are three important classes of biotic components :

1. Producers
2. Consumers
3. Decomposers and transformers.

1. **Producers.** All the green plants of a forest are producers. They are the main sources of food for all the animals. There are several layers of vegetation in the forest. The plants of top stratum are angiospermous and gymnospermous trees. These plants utilize radiant energy of sun to the greatest extent. Below the level of trees there is layer of shrubs which consume light energy of low intensity coming through trees. Just below the shrubs there are grasses, herbs, lichens and mosses. These also manufacture food. These plants get least light.

2. **Consumers.** There are a number of consumers in an old dense forest. Consumers of first order in the forest are grasshoppers, rabbit, deer, monkey, birds and many other wild herbivorous animals which utilize plants directly as their food (Fig. 3.5). Secondary consumers are wolves, pythons, jackals etc. which consume the flesh of herbivores. Lion, tiger, hawks are the consumers of top level.

3. **Decomposers and transformers.** These are micro-organisms, chiefly bacteria and fungi which attack dead bodies or producers and consumers and convert complex organic compounds into simpler inorganic compounds and elements. These free elements again return to the abiotic component and are re-utilised by producers in their nutrition.

Artificial Ecosystems

Gardens, parks, vegetable gardens and agricultural lands are the artificial or man-made ecosystems. A balanced aquarium is also an artificial ecosystem. The space capsule which lasts for limited period is also an artificial ecosystem. For longer journey the spacecraft includes all the basic components of the ecosystem, namely, producers, consumers, decomposers and abiotic components.

Ecological Niches. Species of plants and animals present in an ecosystem perform different functions. Role of each species is spoken of as its niche. In other words, the total role of a species in the community is the ecological niche. The ecological niche includes the species of organisms, environmental factors, the area in which the species live and the specialization of species population within a community. Every population has an ecological niche which determines the structure and adaptation of that population. Ecological niche is not a simple concept but it relates the concepts of population and community. The niche is the property of the community which represents the place of the population in the community structure. Different communities

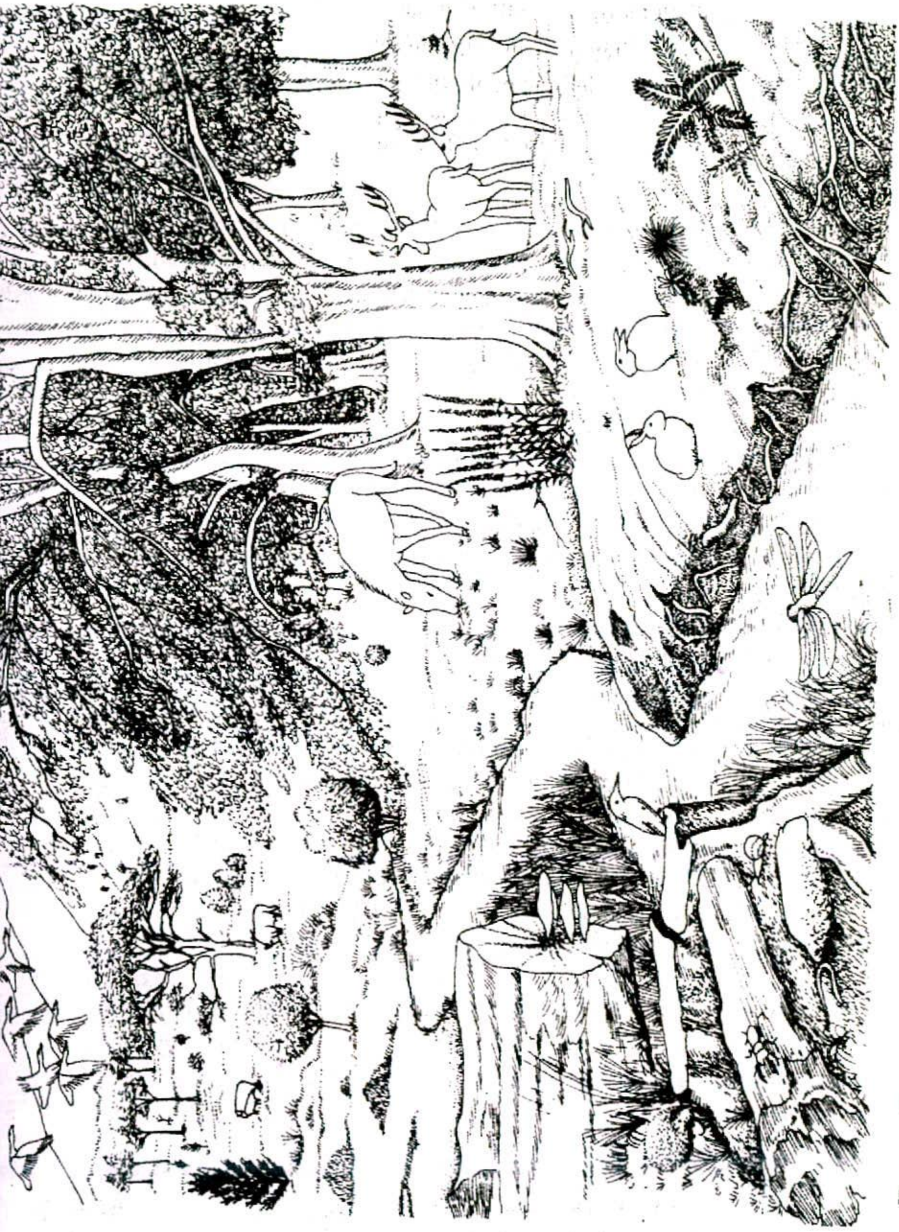

Fig. 3.5. A forest ecosystem.

in ecosystem characterised by similar environments are often similar in their structure and they may contain one or more niches that are essentially identical. The adaptations of population inhabiting these niches may also be similar, even though they are entirely unrelated.

Odum (1971) has classified the ecological niches into following types :

(*i*) **Habitat niches.** These are concerned with habitats of the organisms.

(*ii*) **Trophic niches.** These are related to physiological modifications.

(*iii*) **Geographical niches.** These are related to geographical modifications.

PROCESSES WITHIN THE ECOSYSTEM

In any ecosystem the biotic and abiotic components interact with each other. Processes are the events which either change the form of life or move on the energy and materials within the biotic and abiotic components of ecosystem. The processes operating within the ecosystems may be categorised as under :

1. Metabolic processes of the organisms. These are assimilation, respiration, growth, reproduction, uptake of nutrients and water, transpiration, fixation of nitrogen by bacteria, litter decomposition and mineralisation.

2. Energy flow within the ecosystem.

3. Biogeochemical cycling of minerals, water from abiotic to biotic to abiotic state.

The above processes maintain the dynamic equilibrium between the biotic and abiotic components within an ecosystem. Through metabolic processes the ecosystems become rich in biotic composition, add biomass and store energy in the form of food and maintain an order within the system by pumping out disorders. The second process of energy flow involves transfer of energy from autotrophs to various components of heterotrophs and helps in maintaining the diversity and order within the ecosystem. The third aspect pertaining to the cycling of minerals and water keeps them circulating within the biotic and abiotic components of ecosystem.

ENERGY AND ITS FLOW IN ECOSYSTEM

Energy

Energy has been defined as the capacity to do work. Energy exists in two forms : *potential* and *kinetic*. Potential energy is the energy at rest (*i.e.*, stored energy) capable of performing work. Kinetic energy is the energy of motion (free energy). It results in work performance at the expense of potential energy. Conversion of potential energy into kinetic energy involves the imparting of motion.

The source of energy required by all living organisms is the chemical energy of their food. The chemical energy is obtained by the conversion of the radiant energy of sun. The radiant energy is in the form of electromagnetic waves which are released from the sun during the transmutation of hydrogen to helium. The chemical energy stored in the food of living organisms is converted into potential energy by the arrangement of the constituent atoms of food in a particular manner.

In any ecosystem there should be unidirectional flow of energy. This energy flow is based on two important Laws of Thermodynamics which are as follows :

(1) **The first law of Thermodynamics.** It states that the amount of energy in the universe is constant. It may change from one form to another, but it can neither be created nor destroyed. Light energy can be neither created nor destroyed as it passes through the atmosphere. It may, however, be transformed into another type of energy, such as chemical energy or heat energy. These forms of energy can be transformed into electromagnetic radiation.

(2) **The second law of Thermodynamics.** It states that non-random energy (mechanical, chemical, radiant energy) cannot be changed without some degradation into heat energy. The change of energy from one form to another takes place in such a way that a part of energy assumes waste form (heat energy). In this way, after transformation the capacity of energy to perform work is decreased. Thus, energy flows from higher to lower level.

Main source of energy is sun. Approximately 57% of sun energy is absorbed in the atmosphere and scattered in the space. Some 35% is spent to heat water and land areas and to evaporate water. Of the approximately 8% of light energy striking plant surface, 10% to 15% is reflected, 5% is transmitted and 80 to 85% is absorbed; and an average of only 2% (0.5 to 3.5%) of the total light energy striking on a leaf is used in photosynthesis and rest is transformed into heat energy.

Energy flow in Ecosystems. Living organisms can use energy in several forms : *radiant* and *fixed energy*. Radiant energy is in the form of electromagnetic waves, such as light. Fixed energy is potential chemical energy bound in various organic substances which can be broken down in order to release their energy content.

Organisms that can fix energy from inorganic sources into organic molecules are called autotrophs. Organisms that cannot obtain energy from abiotic source but depend on energy-rich organic molecules synthesised by autotrophs are called heterotrophs. Those which obtain energy from living organisms are called consumers and those which obtain energy from dead organisms are called decomposers (Fig. 3.6).

When the light energy falls on the green surfaces of plants, a part of it is transformed into chemical energy which is stored in various organic products in the plants. When the herbivores consume plants as food and convert chemical energy accumulated in plant products into kinetic energy, degradation of energy will occur through its conversion into heat. When herbivores are consumed by carnivores of the first order (secondary consumers), further degradation will occur. Similarly, when primary carnivores are consumed by top carnivores, again energy will be degraded.

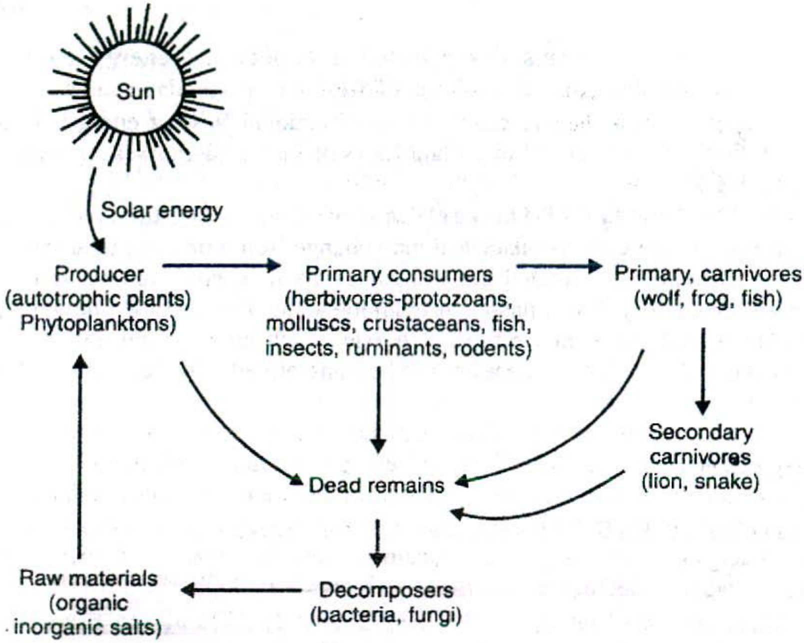

Fig. 3.6. Flow of energy at different levels of ecosystem.

Trophic level. The producers and consumers in ecosystem can be arranged into several feeding groups, each known as *trophic level* (feeding level). In any ecosystem, producers represent the first trophic level, herbivores represent the second trophic level, primary carnivores represent the third trophic level and top carnivores represent the last level.

Food Chain

In the ecosystem, green plants alone are able to trap in solar energy and convert it into chemical energy. The chemical energy is locked up in the various organic compounds, such as carbohydrates, fats and proteins, present in the green plants. Since virtually all other living organisms depend upon green plants for their energy, the efficiency of plants in any given area in capturing solar energy sets the upper limit to long-term energy flow and biological activity in the community. The food manufactured by the green plants is utilized by themselves and also by herbivores. Animals feed repeatedly. Herbivores fall prey to some carnivorous animals. In this way one form of life supports the other form. Thus, food from one trophic level reaches to the other trophic level and in this way a chain is established. This is known as *food chain*. A food chain may be defined as the transfer of energy and nutrients through a succession of organisms through repeated process of eating and being eaten. In food chain initial link is a green plant or producer which produces chemical energy available to consumers. For example, marsh grass is consumed by grasshopper, the grasshopper is consumed by a bird and that bird is consumed by hawk. Thus, a food chain is formed which can be written as follows :

Marsh grass→grass hopper→bird→hawk

Food chain in any ecosystem runs directly in which green plants are eaten by herbivores, herbivores are eaten by carnivores and carnivores are eaten by top carnivores. Man forms the terrestrial links of many food chains.

Food chains are of three types :

1. Grazing food chain
2. Parasitic food chain
3. Saprophytic or detritus food chain

1. **Grazing food chain.** The grazing food chain starts from green plants and goes from herbivores (primary consumers) to primary carnivores (secondary consumers) and then to secondary carnivores (tertiary consumers) and so on. The gross production of a green plant in an ecosystem may meet three fates—it may be oxidized in respiration, it may die and decay and it may be eaten by herbivorous animals. In herbivores the assimilated food can be stored as carbohydrates, proteins and fats, and transformed into much more complex organic molecules. The energy for these transformations is supplied through respiration. Like autotrophs the ultimate disposition of energy in herbivores occurs by three routes : respiration, decay of organic matter by microbes and consumption by the carnivores. The primary carnivores or secondary consumers eat herbivores or primary consumers. Likewise, secondary carnivores or tertiary consumers eat primary carnivores. The total energy assimilated by primary carnivores or gross tertiary production is derived entirely from the herbivores and its disposition into respiration, decay and further consumption by other carnivores is entirely similar to that of herbivores. Thus, it is obvious that much of the energy flow in the grazing food chain can be described in terms of trophic levels as outlined below :

Autotroph→Herbivore→Primary carnivore→Secondary carnivore etc.

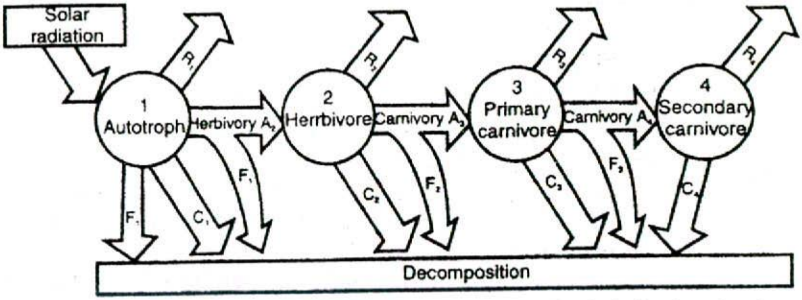

Fig. 3.7. Diagrammatic representation of a grazing food chain showing input and losses of energy at each trophic level. Trophic levels are numbered and used as subscripts to letters indicating energy transfer. A—assimilation of food by the organisms at the trophic level; F—energy lost in the form of faeces and other excretory products; C—energy lost through decay; and R—energy lost to respiration.

A schematic representation of detritus food chain showing input and losses of energy has been presented in Fig. 3.7.

2. **Parasitic food chain.** It goes from large organisms to smaller ones without outright killing as in the case of predator.

3. **Detritus food chain.** The dead organic remains including metabolic wastes and exudates derived from grazing food chain are generally termed **detritus**. The energy contained in detritus is not lost in ecosystem as a whole, rather it serves as a source of energy for a group of organisms called detritivores that are separate from the grazing food chain. The food chain so formed is called **detritus food chain** (Fig. 3.8).

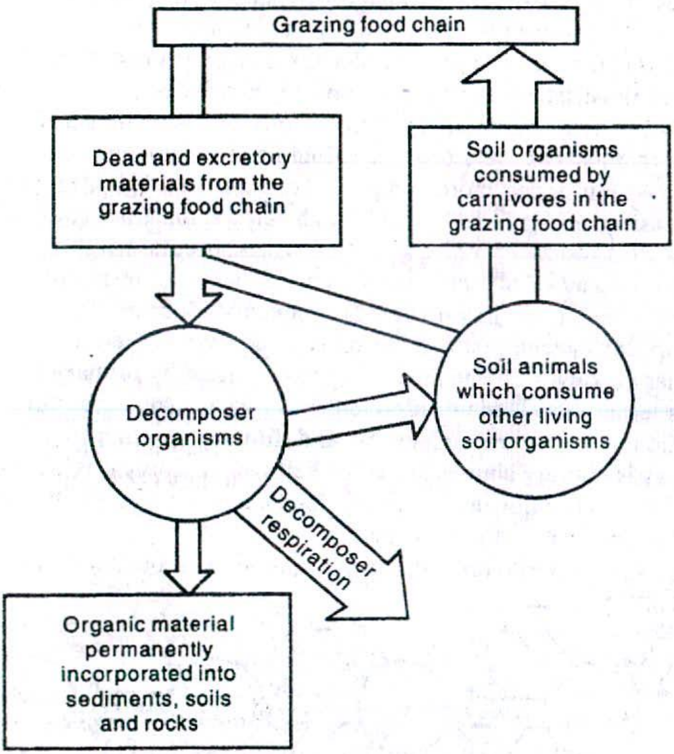

Fig. 3.8. Diagrammatic representation of the detritus food chain showing energy transfers between it and the grazing food chain, as well as energy losses to the detritus food chain.

In some ecosystems more energy flows through the detritus food chain than through grazing food chain. In detritus food chain the energy flow remains as a continuous passage rather than as a stepwise flow between discrete entities. The organisms in the detritus food chain are many and include algae, fungi, bacteria, slime moulds, actinomycetes, protozoa, etc. Detritus organisms ingest pieces of partially decomposed organic matter, digest them partially and after extracting some of the chemical energy in the food to run their metabolism, excrete the remainder in the form of simpler organic molecules. The waste from one organism can be immedia-tely utilized by a second one which repeats the process. Gradually, the complex organic molecules present in the organic wastes or dead tissues are broken down to much simpler compounds, sometimes to carbon dioxide and water and all that are left are humus. In a normal environment the humus is quite stable and forms an essential part of the soil. Schematic representation of detritus food chain is given in Fig. 3.8.

Food web. Many food chains exist in an ecosystem, but as a matter of fact these food chains are not independent. In ecosystem, one organism does not depend wholly on another. The resources are shared specially at the beginning of the chain. The marsh plants are eaten by variety of insects, birds, mammals and fishes and some of the animals are eaten by several predators. Similarly, in the food chain grass→mouse→snakes→owls, sometimes mice are not eaten by snakes but directly by owls. This type of interrelationship interlinks the individuals of the whole community. In this way, food chains become interlinked. A complex of interrelated food chains makes up a **food web**. Food web maintains 'he stability of the ecosystem. The greater the number of alternative pathways the more stable is the community of living things. Fig. 3.9. illustrates a food web in ecosystem.

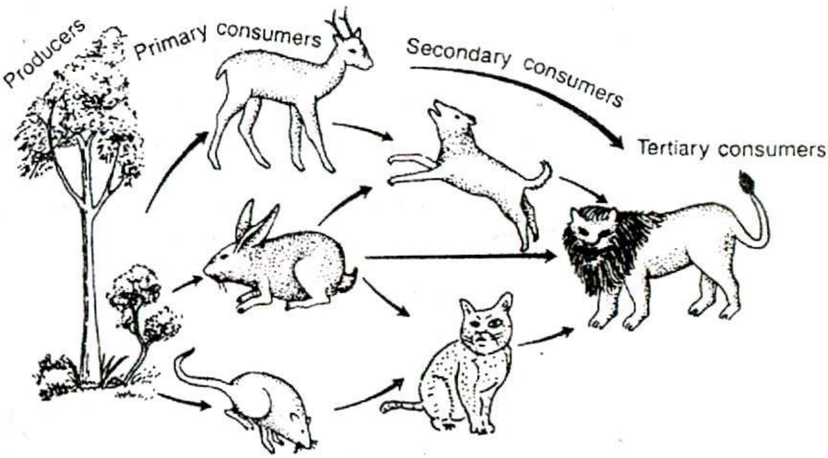

Fig. 3.9. Food web in an ecosystem.

Ecological pyramid. The trophic structure of an ecosystem can be indicated by means of ecological pyramid. At each step in the food chain a considerable portion of the potential energy is lost as heat. As a result, organisms in each trophic level pass on lesser energy to the next trophic level than they actually receive. This limits the number of steps in any food chain to 4 or 5. Longer the food chain the lesser energy is available for final members. Because of this tapering off of available energy in the food chain a pyramid is formed that is known as ecological pyramid. The higher the steps in the ecological pyramid the lower will be the number of individuals and the larger their size.

The idea of ecological pyramids was advanced by C.E. Elton (1927). There are different types of ecological pyramids. In each ecological pyramid, producer level forms the base and successive levels make up the apex. Three types of pyramidal relations may be found among the organisms at different levels in the ecosystem. These are as follows :

1. Pyramid of numbers,
2. Pyramid of biomass (biomass is the weight of living organisms), and
3. Pyramid of energy.

1. **Pyramid of numbers.** It depicts the numbers of individuals in producers and in different orders of consumers in an ecosystem. The base of pyramid is represented by producers which are the most abundant and in the successive levels of consumers, the number of organisms goes on decreasing rapidly until there are a few carnivores. The pyramid of numbers of an ecosystem indicates that the producers are ingested in large numbers by smaller numbers of primary consumers. These primary consumers are eaten by relatively smaller number of secondary consumers and these secondary consumers, in turn, are consumed by only a few tertiary consumers (Fig. 3.10). This type of pyramids is best presented by taking an example of lake ecosystem. In this type of pyramid the base trophic level is occupied by producer elements–algae, diatoms and other hydrophytes which are most abundant. At the second trophic level come the herbivores or zooplanktons which are lesser in number than producers. The third trophic level is occupied by carnivores which are still smaller in number than the herbivores and the top is occupied by a few top carnivores. Thus, in the ecological pyramid of numbers there is a relative reduction in number of organisms and an increase in the size of body from base to apex of the pyramid.

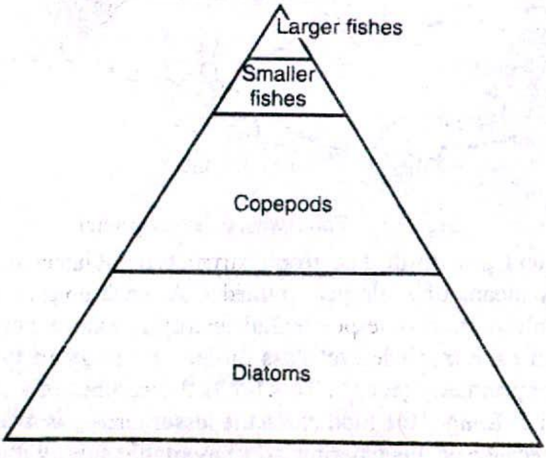

Fig. 3.10. A pyramid of numbers of a lake ecosystem.

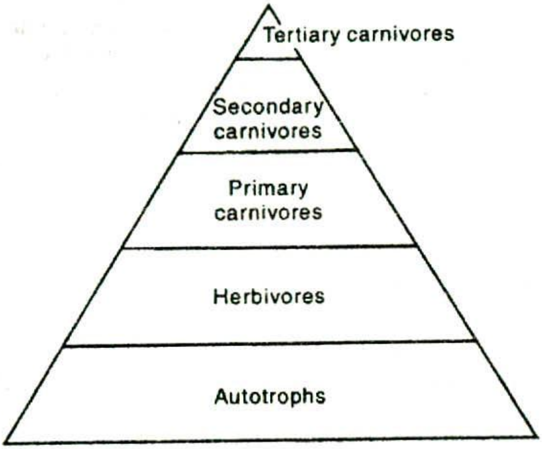

Fig. 3.11. A pyramid of biomass

2. **Pyramid of biomass of organisms.** The living weights or *biomass* of the members of the food chain present at any one time form the pyramid of biomass of organisms. This indicates, by weight or other means of measuring materials, the total bulk of organisms or fixed energy present at one time. Pyramid of biomass indicates the decrease of biomass in each tropic level from base to apex, *e.g.*, total biomass of producers consumed by herbivores is more than the total biomass of the herbivores. Likewise, the total biomass of secondary consumers will be lesser than that of herbivores and so on (Fig. 3.11). Since some energy and material are lost in each successive link, the total mass supported at each level is limited by the rate at which the energy is being stored below. This usually gives sloping pyramid for most of the communities in terrestrial and shallow water ecosystems.

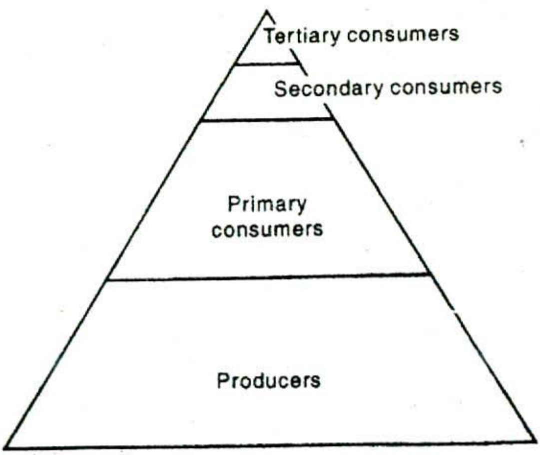

Fig. 3.12. A pyramid of energy

3. **Pyramid of energy.** This depicts not only the amount of total energy utilised by the organisms at each trophic level of food chain but more important, the actual role of various organisms in transfer of energy. At the producer level the total energy will be much greater than the energy at the successive higher trophic level. Some producer organisms may have small biomass but the total energy they assimilate and pass on to consumers may be greater than that of organisms with much larger biomass. Higher trophic levels are more efficient in energy utilization but much heat is lost in energy transfer. Energy loss by respiration also progressively increases from lower to higher trophic states (Fig. 3.12).

In the energy flow process, two things become obvious. Firstly there is one way along which energy moves *i.e. unidirectional flow of energy*. Energy comes in the ecosystem from outside source *i.e.* sun. The energy captured by autotrophs does not go back to the sun, the energy that passes from autotrophs to herbivores does not revert back and as it moves progressively through the various trophic levels, it is no longer available to the previous levels. Thus due to unidirectional flow of energy, the system would collapse if the supply from primary source, the sun is cut off. Secondly, there occurs a progressive decrease in energy level at each trophic level which is accounted largely by the energy dissipated as heat in metabolic activities.

Productivity

The relationship between the amount of energy accumulated and the amount of energy utilised within one trophic level of food chain has an important bearing on how much energy one trophic level passes on to the next trophic level in the food chain. The ratio of output of energy to input of energy is referred to as *ecological efficiency*. Different kinds of efficiencies can be measured by the following parameters :

(*i*) **Ingestion** which indicates the quantity of food or energy taken by trophic level. This is also called **exploitation efficiency.**

(*ii*) **Assimilation** which indicates the amount of food absorbed and fixed.

(*iii*) **Respiration** which indicates the energy lost in metabolism.

The portion of fixed energy, a trophic level passes on to the next trophic level is called **production**. Green plants fix solar energy and accumulate it in organic forms as chemical energy. Since it is the first and basic form of energy storage, the rate at which the energy accumulates in the green plants or producers is known as **primary productivity.** Primary productivity is the rate at which energy is bound or organic material is created by photosynthesis per unit area of earth's surface per unit time. It is most often expressed as energy in calories / cm^2 / *yr* or dry organic matter in g / m^2 / yr ($g/m^2 \times 8.92 = lb$ / acre). The amount of organic matter present at a given time per unit area is called **standing crop** or **biomass** and as such productivity, which is a rate, is quite different from biomass or standing crop. The standing crop is usually expressed as dry weight in g/m^2 or kg/m^2 or as *t/ha* (metric tons), 10^6 *g*/hectare. Primary productivity is the result of photosynthesis by given plants including algae of different colours. Bacterial photosynthesis or chemosynthesis, although of small significance may also contribute to primary productivity. The total solar energy trapped in the food material by photosynthesis is referred to as **gross primary productivity (G.P.P.).**

A good fraction of gross primary production is utilized in respiration of green plants. The amount of energy bound in organic matter per unit area and time that is left after respiration of these plants is **net primary production (N.P.P.)** or **plant growth.** Only the net primary productivity is available for harvest by man and other animals.

Net productivity of energy = gross productivity—energy lost in respiration. The rates at which the heterotrophic organisms resynthesize the energy-yielding substances is termed as *secondary productivity.* Secondary productivities are the productivities of animals and saprobes in communities.

Environmental factors affecting the production processes in an ecosystem are as follows :

1. **Solar radiation and Temperature**
2. **Moisture.** Leaf water potential, soil moisture and precipitation fluctuation and transpiration.
3. **Mineral nutrition.** Uptake of minerals from the soil, rhizosphere effects, fire effects, salinity, heavy metals, nitrogen metabolism.
4. **Biotic activities.** Grazing, above ground herbivores, below ground herbivores, predators and parasites, diseases of primary producers.
5. **Impact of human population.** Pollutions of different sorts, ionizing radiations like atomic explosions, etc.

There are three fundamental concepts of productivity :

1. Standing crop
2. Materials removed
3. Production rate.

1. **Standing crop.** It is the abundance of the organisms existing in the area at any one time. It may be expressed in terms of number of individuals, as biomass of organisms, as energy content or in some other suitable terms. Measurement of standing crop reveals the concentration of individuals in the various populations of the ecosystem.

2. **The materials removed.** The second concept of productivity is **the materials removed** from the area per unit time. It includes the yield to man, organisms removed from the ecosystem by migration, and the material withdrawn as organic deposit.

3. **The production rate.** The third concept of productivity is the **production rate.** It is the rate at which the growth processes are going forward within the area. The amount of material formed by each link in the food chain per unit of time per unit area or volume is the production rate.

All the three major groups of organisms—producers, consumers and reducers are the functional kingdoms of natural communities. The three represent major directions of evolution and are characterised by different modes of nutrition. Plants feed primarily by photosynthesis, animals feed primarily by ingesting food that is digested and absorbed in the alimentary canal and the saprobes feed by absorption and have need for an extensive surface of absorption. The principal kinds of organisms among saprobes are the unicellular bacteria, yeasts, chytrids of lower fungi and higher fungi with mycelial bodies.

In terrestrial communities as much as 90% of net primary production remains unharvested and are utilized as dead tissue by saprobes and soil animals. The saprobes have a larger and more essential role than animals in degrading dead organic matter to inorganic forms and in such ecosystems, secondary production by reducers (decomposers) should exceed that by consumers, though the former is even more difficult to measure than the latter. Biomass of decomposers with their microscopic cells and filaments embedded in food sources is also difficult to measure and that is small in relation to their productivity and significance for the ecosystem. Small masses of reducers degrade and transform far larger masses of organic matter to inorganic remnants. In so doing decomposers disperse back to the environment the energy of photosynthesis accumulated in the organic compounds that decompose. Thus they have a major role in the energy flow of ecosystems. A community or ecosystem, like an organism, is an open energy system. The continuous intake of energy in photosynthesis replaces the energy dissipated to environment by respiration and biological activity and the system does not run-down through the loss of fee energy to maximum entropy. If the amount of energy entrapped is greater than the energy dissipated, the pool of biologically useful energy of organic bonds increases. This results in increase of community biomass and consequently the community grows; such is the case in succession. If energy intake is less than energy dissipation, the community biomass will decrease and it must, in some sense, retrogress. If energy intake and loss are in balance, the pool of organic energy is in steady state; such is the case in climax communities. Three aspects of this steady state may be recognised :

(*i*) The steady state of population of climax communities in which equal birth and death rates in population keep the number of individuals relatively constant,

(*ii*) The steady state of energy flow,

(*iii*) The steady state of the matter of community, where addition of material by photosynthesis and organic synthesis is balanced by loss of material through respiration and decomposition.

Methods of Measuring Primary Production

There are several parameters for measuring primary production and the methods of measuring primary production are based on those parameters. The methods are discussed here as under :

1. **Harvest method.** It involves removal of vegetation periodically and weighing the material. For measuring above ground production, the above ground plant parts are clipped at ground level, dried to constant weight at 80°C and weighed. The dry weight in g/m^2/year gives the ground production.

Below ground production is estimated by using frequent core sampling technique of Dahlman and Kucera (1965). It is expressed in terms of weight in gm per unit area per year. In terms of energy one gm dry weight of plant material contains 4 to 5 kcal. The limitations of harvest method are as follows :

(*i*) The amount of plant material consumed by herbivores and the food oxidised during respiration process of the plants is not accounted.

(*ii*) Root biomass is neglected.

(*iii*) Photosynthates translocated to underground parts of plants are not known.

In spite of these limitations the method is used allover for measuring net assimilation rate (NAR) and relative growth rate (RGR).

2. **Carbon dioxide assimilation method.** Utilization of CO_2 in photosynthesis or its liberation during respiration is measured by infrared gas analysis or by passing the gas through Baryta water $Ba(OH)_2$ and titrating the same. The CO_2 removed from incoming gas chamber is taken to be synthesized into organic matter by the green plants. Performing the experiment in light and dark chambers the net and gross production can be measured. In the lighted chamber photosynthesis and respiration take place simultaneously and the CO_2 coming out from the chamber is the unused gas of the atmosphere plus gas from the respiration of plant parts. In the dark chamber all CO_2 is due to respiration.

Net production = Gross production—Respiration

3. **Oxygen production method.** In the aquatic vegetation CO_2 gas analysis method is not used but oxygen evolution method is generally used. The light and dark bottle technique is employed for measuring primary production of aquatic plant. In this method two bottles, one transparent and the other opaque are filled with water at a given depth of lake, closed, maintained at that depth for sometime and then brought in laboratory for determination of oxygen content in the water. The decrease of oxygen in dark bottle is due to respiratory activity while increase of O_2 in light bottle is due to photosynthesis. The total increase of O_2 in light bottle plus the amount of O_2 decreased in dark bottle express gross productivity (O_2 value multiplied by 0.375 gives an equivalent of carbon assimilation). Recently, oxygen electrodes have been used for estimating oxygen content in water.

4. **Chlorophyll method.** Gesner (1949) pointed out that the amount of chlorophyll/m^2 is almost limited to a narrow range of 0.1 to 3.0 gm regardless of the age of individuals or the species present therein. There is direct correlation between the amount of chlorophyll and dry matter production in different types of communities with varying light conditions. The relation

of total amount of chlorophyll to the photosynthetic rate is referred to as **assimilation ratio** or rate of production/gm chlorophyll. Total chlorophyll per unit area is greater in land plants as compared to that in aquatic plants. In marine ecosystem the rate of carbon assimilation is 3.7 g/hr/g of chlorophyll. The relationship between area based chlorophyll and dry matter production in terrestrial ecosystems has been worked out by Japanese ecologists Argua and Monsi (1963).

5. **Other methods.** Pandeya (1971), Sharma (1972) and several other ecologists have evolved correlation coefficients for evaluating biomass and productivity in forest trees by measuring their diameter at breast height (DBH), height, canopy cover, etc. Methods of establishing regression are as below :

(*i*) Diameter of trees in sample quadrats is measured at breast height and the height repeated is determined for each tree.

(*ii*) Different diameter and height classes are determined for each species.

(*iii*) A set of sample trees is cut and subjected to a detailed analysis for dry weight of stems, twigs, leaves and roots.

(*iv*) Regression values are computed for the sets of trees belonging to each girth class, relating the biomass of each fraction to the diameter at breast height.

(*v*) The regression values are used to compute the probable biomass and production of each tree in the sample area. These values for each species when pooled give biomass and production rate of trees per unit area in the forest.

Age of the trees markedly influences the annual net production.

BIOGEOCHEMICAL CYCLES

Nearly 30 to 40 elements are required for proper growth and development of living organisms. Most important of these are C, H, O, P, K, N, S, Ca, Fe, Mg, B, Zn, Cl, Mo, Co, I and F. These materials flow from abiotic to biotic components and back to the non-living component again in a more or less cyclic manner. This is known as the biogeochemical cycle or inorganic-organic cycle. The flow of these elements through the ecosystem must be cyclic, with matter being consistently reused. Because the flow involves not only the living organisms but also a series of chemical reactions in the abiotic environments, these cycles are called biogeochemical cycles.

There are three types of biogeochemical cycles :

(1) Hydrologic cycle or water cycle,

(2) Gaseous cycles, and

(3) Sedimentary cycles.

1. Hydrologic or Water Cycle

Interchange of water between atmosphere, land and sea and between living organisms and their environment is accomplished through water cycle. Water cycle or hydrologic cycle involves evaporation, transpiration, cloud formation and precipitation. Water of atmosphere reaches the earth

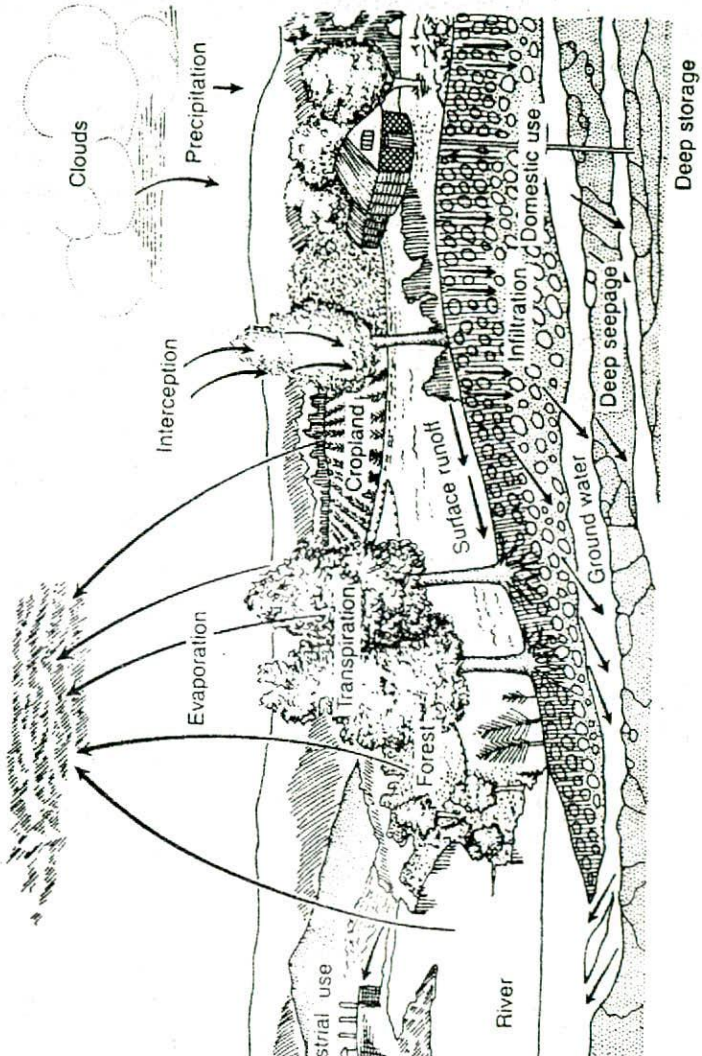

Fig. 3.13. The water cycle, showing the major pathways of water through the ecosystem.

surface through precipitation and from the earth surface it reaches the atmosphere through evaporation and transpiration. The amount of water available for evaporation is determined by the amount supplied by precipitation and condensation. Between rainfall input and evaporation output there lies a precarious water balance (Fig. 3.13).

2. Gaseous Cycles

Oxygen cycle. Oxygen is found in free state in atmosphere and in dissolved state in water. It is liberated as by-product of photosynthesis and is utilized in respiration by all the plants and animals. When the living organisms respire, CO_2 is liberated which is utilized by green plants as an essential raw material for carbohydrate synthesis. In this way, a simple yet vital O_2 cycle is maintained in the ecosystem (Fig. 3.14).

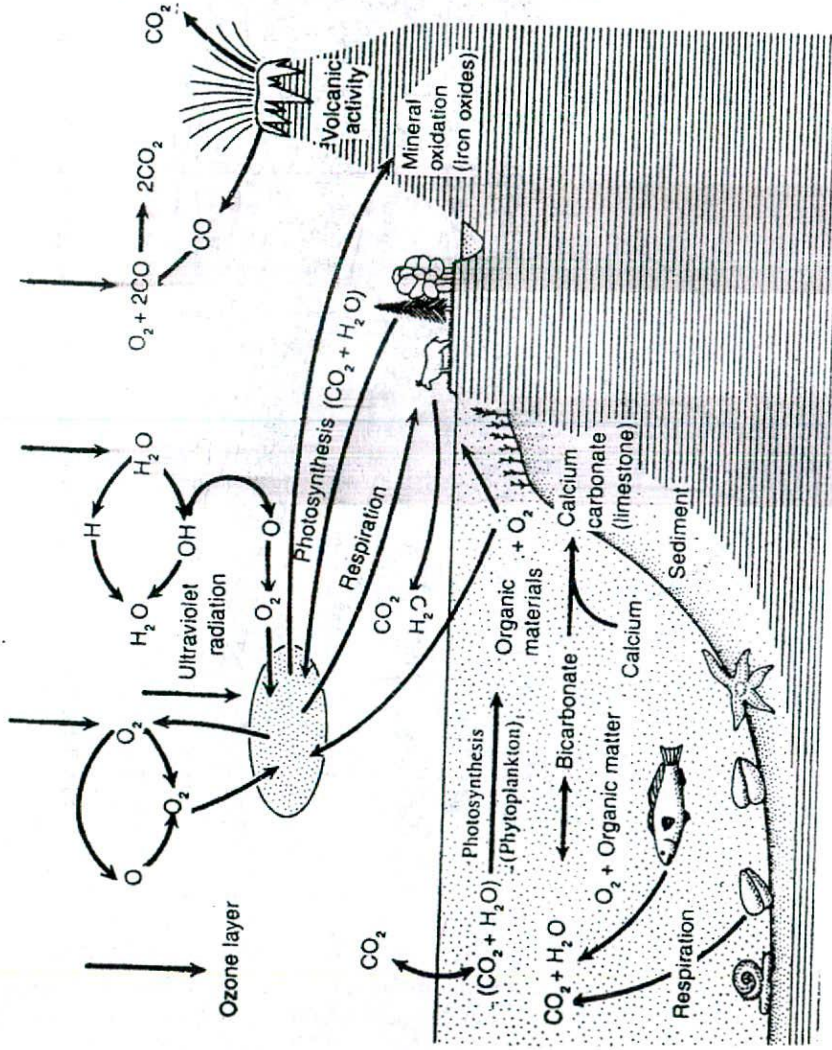

Fig. 3.14. Oxygen cycle.

Carbon cycle. Carbon is the basic constituent of all organic compounds. Since energy transfer occurs in the consumption and storage of carbohydrates and fats, carbon moves to the ecosystem with flow of energy. The source of nearly all carbon found in the living organisms is CO_2 which is found in free state in atmosphere and in dissolved state in the water on the earth. Green plants (producers) use CO_2 through photosynthesis in the presence of sunlight and carbohydrate is formed. Later on, complex fats and polysaccharides are formed in plants which are utilised by animals. Flesh eating animals (carnivores) feed on herbivores and the carbon compounds are again digested and converted into the other forms. Carbon is released to the atmosphere directly as CO_2 in respiration of both plants and animals. Bacteria and fungi attack the dead remains of plants and animals. They degrade the complex organic compounds into simple substances which are then available for other cycles. Part of the organic carbon becomes incorporated into the earth's crust as coal, gas, petroleum, limestone and coral reef. Carbon from such deposits may be liberated after a long period of time (Fig. 3.15).

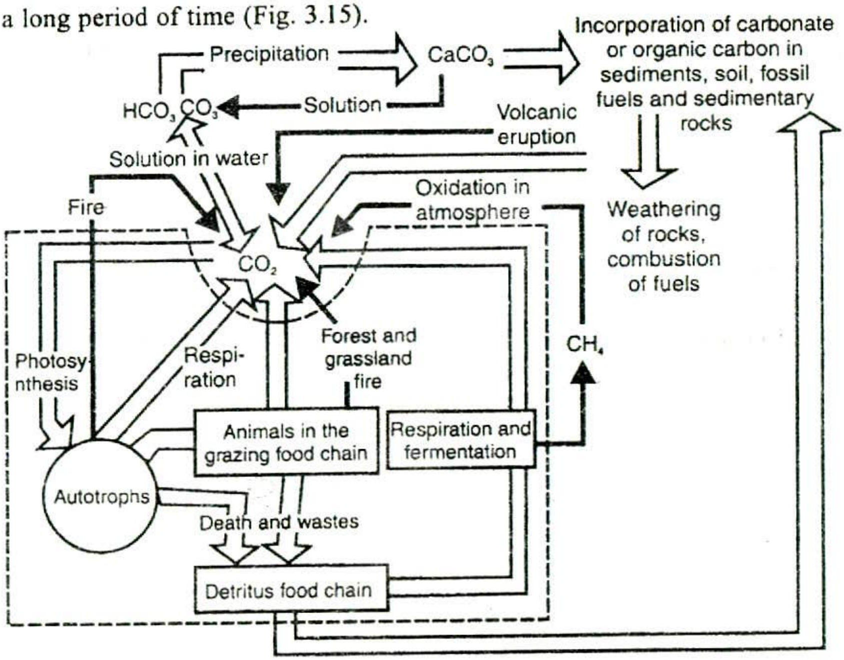

Fig. 3.15. Carbon cycle in nature.

Nitrogen cycle. Of all the elements which plants absorb from the soil, nitrogen is the most important for plant growth. This is required in greatest quantity. Nitrogen is required for the synthesis of aminoacids, proteins, enzymes, chlorophylls, nucleic acids, etc. Green plants obtain nitrogen from the soil solution in the form of ammonium, nitrate and nitrite ions and the main source of all these nitrogen compounds is the atmospheric nitrogen.

The atmospheric nitrogen is not directly available to the organisms with the exception of some prokaryotes like blue green algae and nitrogen fixing bacteria. Nitrogen cycle consists of the following steps :

(1) Nitrogen fixation, (2) Nitrogen assimilation, (3) Ammonification, (4) Nitrification, (5) Denitrification, and (6) Sedimentation.

1. **Nitrogen fixation.** Conversion of free nitrogen of atmosphere into the biologically acceptable form or nitrogenous compounds is referred to as nitrogen fixation. This process is of two types :

(*a*) **Physicochemical** or non-biological nitrogen fixation

(*b*) **Biological nitrogen fixation.**

In physicochemical process of nitrogen fixation, atmospheric nitrogen combines with oxygen (as ozone) during lightning or electrical discharges in the clouds and produces different nitrogen oxides :

$$N_2 + 2\,(O) \xrightarrow{\text{Electric}} 2NO$$
$$2NO + 2\,(O) \xrightarrow{\text{Discharge}} 2NO_2$$
$$2NO_2 + (O) \longrightarrow N_2O_5$$

The nitrogen oxides get dissolved in rain water and on reaching earth surface they react with mineral compounds to form nitrates and other nitrogenous compounds :

$$N_2O_5 + H_2O \longrightarrow 2HNO_3$$
$$2HNO_3 + CaCO_2 \longrightarrow Ca\,(NO_3)_2 + CO_2 + H_2O$$

During combustion of various types, some nitrogenous compounds are formed which are washed down along with rain water. At high pressure and temperature, nitrogen and hydrogen react to form ammonia (industrial nitrogen fixation).

Biological nitrogen fixation is carried out by certain prokaryotes. Some blue-green algae fix significant amounts of nitrogen in the oceans,

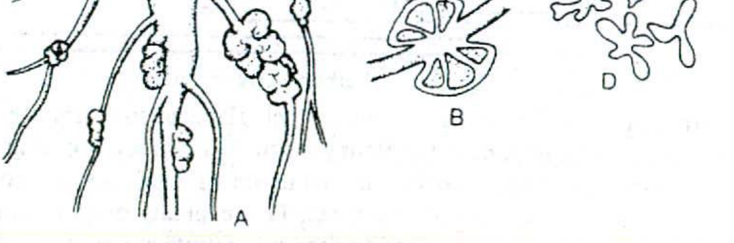

Fig. 3.16 Root nodules of a legume plant. A—Legume root with nodules. B—T.S. of root-nodule. C—Single cell of nodule. D—Nitrogen-fixing bacterium, *Rhizobium*.

lakes and soils. Symbiotic bacteria (*Rhizobium*) inhabiting the root nodules of legumes (Fig. 3.16) and also the species of alder, buckbrush and a number of other non-leguminous genera and symbiotic blue-green algae (species of *Nostoc, Anabaena,* etc.) found in free state or in the thalli of *Anthoceros, Salvenia, Azolla,* coralloid roots of *Cycas* fix atmospheric nitrogen. The relation is mutualistic because the microbes use energy from the plants to fix nitrogen that is made available to the host plants and other plants of the community. Certain free living nitrogen fixing bacteria, such as *Azotobacter, Clostridium, Beijerinckia, Derxia, Rhdospirillium* also fix free nitrogen of atmosphere in the soil. *Frankia,* an actinomycetous fungus found in the roots of *Alnus, Percia, Casuarina,* etc. also fixes nitrogen. Nitrogen fixing organisms combine the gaseous nitrogen of atmosphere with hydrogen obtained from respiratory pathway to form ammonia which then reacts with organic acids to form aminoacids. Biological nitrogen fixation is the major source of fixed nitrogen upto 140—700 mg/m^2/year as against 35 mg/m^2/year by electrical discharge and photochemical fixation.

2. **Nitrogen assimilation.** Inorganic nitrogen in the form of nitrates, nitrites and ammonia is absorbed by the green plants and converted into nitrogenous organic compounds. Nitrates are first converted into ammonia which combines with organic acids to form aminoacids. Aminoacids are used in the synthesis of proteins, enzymes, chlorophylls, nucleic acids, etc. Animals derive their nitrogen requirement from the plant proteins. Plant proteins are not directly utilized by the animals. They are first broken down into amino acids during digestion and then the amino acids are absorbed and manipulated into animal proteins, nucleic acids, etc.

3. **Ammonification.** The dead organic remains of plants and animals and excreta of animals are acted upon by a number of microorganisms especially actinomycetes and bacilli (*Bacillus ramosus, B. vulgaris, B. mesenterilus*). These organisms utilize organic compounds in their metabolism and release ammonia.

4. **Nitrification.** Certain bacteria, such as *Nitrosomonas, Nitrococcus, Nitrosogloea* and *Nitrospira* in oceans and soils convert ammonia into nitrites and then nitrites into nitrates. These bacteria primarily use the energy of dead organic matter in their metabolism.

$$2NH_4^+ + 2O_2 \longrightarrow NO_2^- + 2H_2O + \text{energy}$$

Conversion of nitrites to nitrates is brought about by several microbes like *Penicillium* species, Nitrobacter, *Nitrocystis* etc. *Nitrocystis oceanus* is the common marine autotroph which performs nitrification for obtaining energy.

$$2NO_2^- + O_2 \longrightarrow 2NO_3^- + \text{energy}$$

Some nitrates are also made available through weathering of nitrate containing rocks.

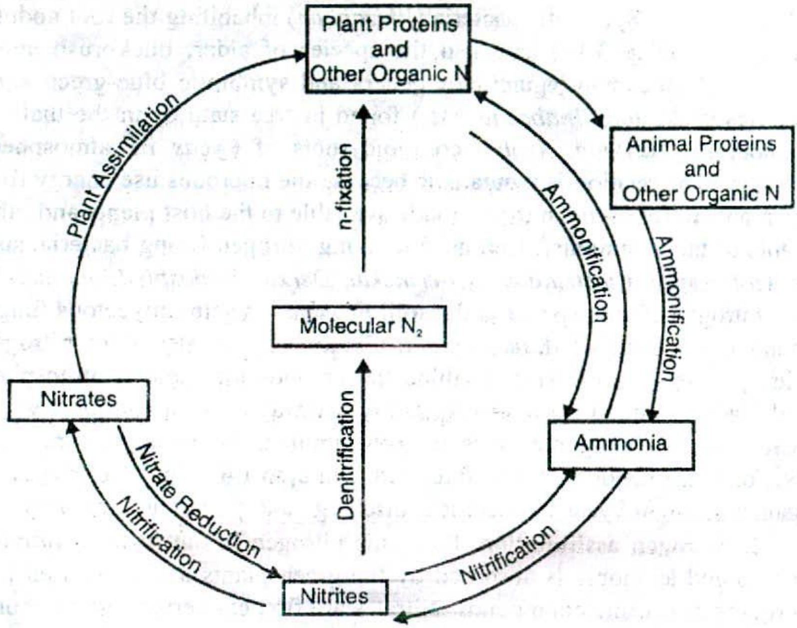

Fig. 3.17. The nitrogen cycle in ecosystem.

5. **Denitrification.** Ammonia and nitrates are converted into free nitrogen by certain microbes. This process is referred to as **denitrification.** *Thiobacillus denitrificans, Micrococcus denitrificans, Pseudomonas aeruginosa* are the common examples of denitrifying bacteria.

$$2NO^-_3 \longrightarrow 2NO^-_2 \longrightarrow 2NO \longrightarrow N_2O \longrightarrow N_2$$

6. **Sedimentation.** Nitrates of the soil are washed down to the sea or leached deep into the earth along with percolating water. Nitrates thus lost from the soil surface are locked up in the rocks. This is sedimentation of nitrogen. Nitrogen of rock is released only when the rocks are exposed and weathered.

Thus a large part of nitrogen is fixed up and stored in plants, animals, and microbes. Nitrogen leaves the living system in the same amount is taken in from the atmosphere and the input and outflow of nitrogen are balanced in the ecosystem. The overall nitrogen cycle in nature is presented in Fig. 3.17.

3. Sedimentary Cycles.

Mineral elements required by living organisms are obtained initially from inorganic sources. Available forms occur as salts dissolved in soil water. Mineral cycles essentially consist of two phases : (*i*) the salt solution phase, and (*ii*) rock phase.

Mineral salts come directly from earth crust by weathering. Soluble salts then enter the water cycle. By movement of water minerals move from the soil to streams, lakes and ultimately to sea where they remain permanently.

Other salts return to the earth's crust through sedimentation. They become incorporated into sediments or rock beds and after weathering of rocks they again enter the cycle. Plants and some animals take minerals in the form of mineral solution from their habitats. After the death of living organisms the nutrients return to the soil and water through the action of decomposers (bacteria and fungi) and transformers. Green plants at one end and decomposers at the other play very important role in circulation of nutrients.

Phosphorus cycle. Plants and animals obtain phosphorus from the environment. Phosphorus is a component of nucleic acids, ADP, ATP, NADP, phospholipids etc. It occurs in the soil as rock phosphate, apatite or calcium phosphate, fluorapatite [$Ca_{10}Fe_2$ $(PO_4)_6$], iron phosphate or aluminium phosphate. Soils derived from the rock beds rich in phosphates are rich in phosphorus.

Phosphorus occurs in the soil in five forms: P_1 (stable organic), P_2 (labile organic), P_3 (labile inorganic), P_4 (soluble) and P_5 (mineral form) and of these forms, P_3 and P_4 are in equilibrium and entry of phosphorus in the green plants is considered to occur via labile inorganic pool.

The dissolved phosphorus is absorbed by plants and converted to organic form. From plants it travels to various trophic levels in the form of organic phosphates. When the plants and animals die the decomposers attack them and liberate phosphorus to the environment. Thus, this process proceeds in cyclic way. A general picture of the phosphorus cycling is presented in Fig. 3.18.

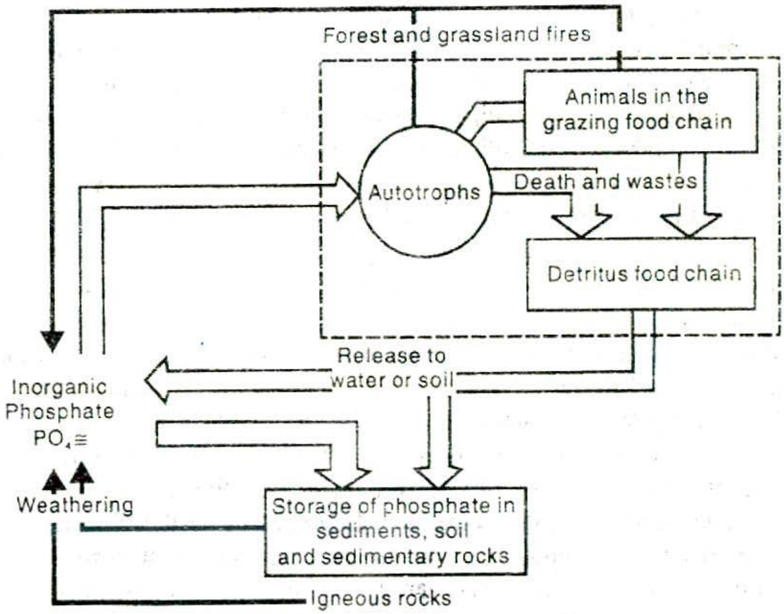

Fig. 3.18. Phosphorus cycle in ecosystem.

Phosphorus along with many other mineral elements reaches the oceans and settles down as sediment. A good proportion of phosphorus leaches down to deep layers of soil. In this way, major proportion of phosphate becomes lost to this cycle by physical processes, such as sedimentation and leaching. Biological processes such as formation of teeth and bones also keep phosphorus locked up for some time.

Sulphur Cycle. Sulphur cycle links soil, water and air. Sulphur occurs in the soil and rocks as sulphides (FeS, ZnS, etc.) and crystalline sulphates. In the atmosphere sulphur occurs in the form of SO_2 and H_2S. SO_2 gas is formed during combustion of fossil fuels or as a result of decomposition. H_2S or hydrogen sulphide gas is released to the atmosphere from water logged soils, continental shelf, lakes and springs. The organic and inorganic sulphur and SO_2 are formed through oxidation of H_2S in the atmosphere. A small amount of sulphur occurs in dissolved state in rain water and through rains it reaches earth surface. Except a few organisms which need organic form of sulphur as amino acids and cystein, most of the organisms take sulphur as inorganic sulphates. Most of the biologically incorporated sulphur is produced in the soil from aerobic breakdown of proteins by bacteria and fungi. Under an aerobic condition, however, sulphur may be reduced directly to sulphides, including H_2S.

$$2H_2S + O_2 \xrightarrow{\textit{Baggiatoa spp.}} 2S + 2H_2O$$

$$2S + 2H_2O + 3O_2 \xrightarrow[\text{(Thio - oxidation)}]{\textit{Thiobacillus}} 2H_2SO_4$$

Green and purple photosynthetic bacteria use hydrogen of H_2S as the oxygen acceptor in reducing carbon dioxide. Green bacteria are able to oxidise sulphide to elemental sulphur whereas the purple bacteria can carry oxidation to sulphate stage. In the ecosystems, sulphur is transferred from autotrophs to animals, then to decomposers and finally it returns to environment through the decay of dead organic remains (Fig. 3.19).

Sedimentary aspect of sulphur cycling involves precipitation of sulphur in presence of iron under anaerobic conditions. Sulphides of iron, copper, zinc, cadmium, cobalt are insoluble in neutral and alkaline water and consequently sulphur is bound to limit the amount of these elements. Thus, sulphur cycle affords an excellent example of interaction and complex biochemical regulation between the different mineral cycles.

The study of biogeochemical cycles in the ecosystem makes it clear that the abiotic components of ecosystem are transformed into biotic structures through metabolic processes and locked up in the biomass for some time depending upon the turnover rate. In lower plants with soft tissues the turnover rate is quicker than in higher plants and animals. The materials held up in the biomass are released to the environment by decomposing activities.

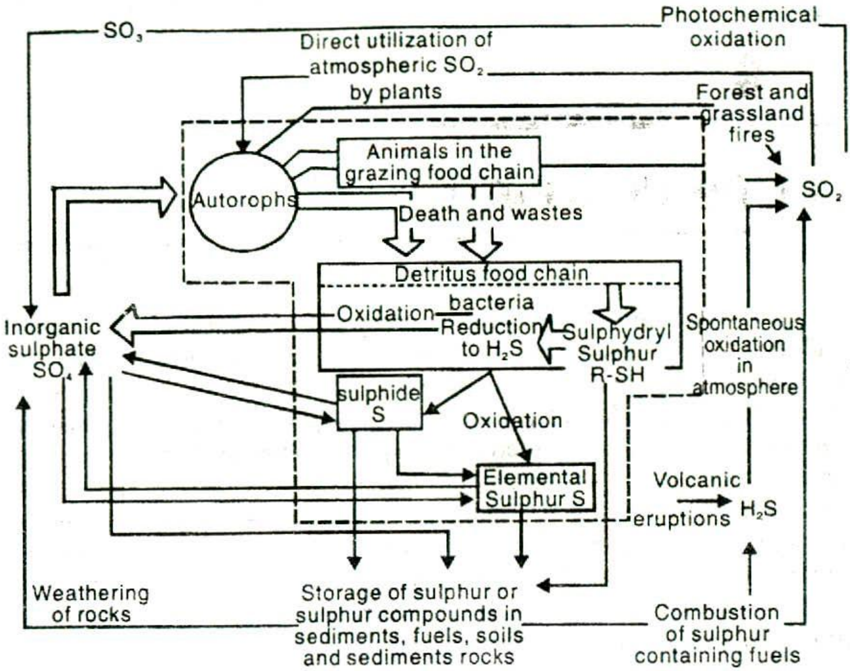

Fig. 3.19. Sulphur cycle. Organic phase is shown within broken lines.

The nutrient cycle is not a close circuit within an ecosystem. The nutrients are continuously being imported as well as carried out of the ecosystem. Appreciable quantities of plant nutrients are brought to ecosystem by rain and snow. Small quantity of nutrients is carried to the forest by rains. The gain of nutrients to the ecosystem from precipitation, extraneous material and mineral weathering is offset by losses. Water draining away from forest carries with it more mineral matter than supplied through precipitation. Considerable quantities of nutrients in the forest are locked up in the trees and the humus layer. When trees and vegetation are removed, sufficient amounts of nutrient are removed. Intensive forestry and agriculture on some soils may reduce the nutrient reserves to such an extent that soils become unfertile. Ecosystem can remain productive only if the nutrients withdrawn are balanced by an inflow or replacement.

QUESTIONS

1. What is ecosystem? What are the various components of ecosystem?
2. What are the major ecosystems of the world? Describe forest and pond ecosystems in detail.
3. What is meant by energy flow in an ecosystem? What are the laws of thermodynamics?
4. Write short notes on the following :
   Producers, Food chain and Food web, Ecological pyramids, Hydrologic cycle, Nitrogen cycle, Productivity, Ecological niches.

4

AUTECOLOGY

An ecosystem usually contains numerous species of plants, animals and microbes. A **species** includes individuals which are usually alike and capable of interbreeding and producing fertile offsprings. A group of interacting and interbreeding individuals of a species found in a particular surrounding or locality is referred to as **population.** A branch of ecology which is concerned with the study of individual species at all stages of its life cycle in relation to its environment is called **autecology or species ecology.** This branch of ecology aims at the study of life cycle, distribution, differentiation, ecological relationships, adaptation and genetic variability of population of individual species in relation to its environment. Autecology provides a sound basis for synecology as it helps in explaining the structure and dynamics of communities by way of providing informations regarding the ecology of important species of communities. In the words of C.F. Harried II (1977), "the two types of study, autecology and synecology are inter-related, the synecologist painting with a broad brush the outline of the picture and autecologist stroking in the finer details." Much stimulus for autecological studies has come mainly from the economic importance of certain species and agronomy and silviculture are, indeed, applied aspects of autecology. Several plant species introduced from one country to the other countries where they never existed have become fully acclimatised and are creating serious problems in agriculture. The knowledge of autecology of those species may definitely be helpful in eradication or control of the species.

Ecological Life History of Species

Several eminent workers have prepared detailed scheme for a systematic study of autecological life histories. Stevens and Rock (1952) have suggested scheme for autecological life histories of herbaceous plants. Pelton (1951) has given a scheme for the study of autecological life histories of trees, shrubs and stem succulents; Curtis (1952) for vascular epiphytes, and Cooke (1951) for fungi and they have emphasized the need for study of environment and performance of plants. The main purpose of such studies should be to uncover the response of various forms of life to stimuli and compulsions of environment, and also to throw light on the limits of its geographical distribution and causes related to this. The different aspects in the study of autecology of an individual species are outlined below :

(1) In any ecological or botanical study identification of plants is the first requisite. Taxonomy and nomenclature of the species under study are discussed. Under nomenclature scientific valid names, various synonyms and common names are discussed. The confirmation of identification is advisable in a standard regional or central herbarium. The botanical survey of India has developed a chain of herbaria; Central National Herbarium at Sibpur, Howrah, and Regional Herbaria at Poona, Coimbatore, Shillong, Dehradun and Allahabad. Besides, a small Economic plant herbarium exists at Central Botanical Laboratory, Calcutta. These herbaria maintain large collections of correctly identified and properly arranged plants specimens and run a plant identification service.

Associates. The species associated with the plant species under study should be recorded in a number of habitat conditions in order to get a proper range of variations, Associate species indicate the sociability and adaptations of a plant.

(2) **Distribution and importance.** The range of distribution, altitudinal and latitudinal limits and its ecological importance in various regions and habitats are noted. The degree of dominance or subdominance of species in different types of vegetation; its place in succession, whether pioneer or seral member or a component of climax community; its economic importance for browse, timber, pulp, fruits, in erosion and medicine are emphasized.

(3) **Morphology of plants.** In this, the distinguishing features of various plant parts are described. Structural variations are also noted in the plants of same species growing on the different ecological habitats.

(4) **Cytogenetics of plant species.** Cytological features, such as the structure of cytoplasm, chromosome morphology and the number and behaviour of chromosomes during mitosis and meiosis are studied in detail. Sometimes plants of the same species growing geographically isolated become so much differentiated and morphologically changed that they are often supposed as separate species. In such cases, interbreeding experiments are made. If the individuals interbreed, it is supposed that they belong to the same species. Variations in nature and factors for segregation are also discussed.

(5) **Physiology of plant.** Various physiological processes of the plants of the particular species are studied in detail and the factors influencing the rates of those processes are also taken into consideration.

(6) **Environmental complex.** The life cycle of individual species is greatly influenced by a number of environmental factors operating in conjunction as environmental complex. The various stages of life cycle of plant species in nature remain completely embedded in the environmental complex. Different species differ in respect of their response to climatic factors at different stages of their life cycles. Each species has a definite

time (month or season) in the year for seed germination, seedling growth, vegetative growth, flowering and fruiting etc. Study of all these processes of species in relation to different periods or seasons of the year is called its **phenology.** Since each species has a definite period for a particular stage of its life history, presence of species in that particular stage will indicate the time of the year. In other words, the phenological behaviour of the species and different environmental factors at different seasons of the year are so much interlinked that the species is said to be **biological** or **ecological clock**. In autecology of a species both biotic and abiotic aspects are measured quantitatively at different stages of plant growth at regular intervals in order to study the phenology (germination, leaf-fall, initiation of flower bud, etc.) in relation to different seasons of the year. The environmental complex which is made up of several factors in various combinations affects each stage of plant's life cycle. In the foregoing discussion correlations of phenology to the various environmental changes are discussed :

(1) **Flowering.** Various environmental factors, such as, light, temperature of the soil and atmosphere, percentage of nutrients in the soil, etc. affect the flowering process, of plants. In autecology of a species, the period of flowering as well as the specific roles of different environmental factors on flower initiation, is noted. The photoperiodic effects and temperature effects on the flowering are studied in detail.

(2) **Pollination.** During pollination, the environmental factors help the plant to a great extent. Some plants may be pollinated by wind, some by water and some others by biotic agencies, such as insects, birds and even man.

(3) **Fruiting.** The structure and number of fruits, number of seeds per fruit, season of fruiting, etc. are some of the important aspects in study of ecological life cycle of a species. The environmental factors by way of their influence on the fruiting of the plants determine the success or failure of particular species of the community in regeneration and establishment. Biotic factors, especially certain disease causing fungi and insects, damage fruits and thus affect fruit formation to a great deal.

(4) **Seed output.** The number of seeds produced by a plant in one reproductive flux is known as *seed output.* The seed output is measured by the following methods :

Average number of seeds per fruit	$= a$
Average number of fruits per plant	$= b$
Average seed output	$= (a \times b)$
Average number of fruits per branch (for trees and shrubs)	$= b_1$
Average number of branches per plant	$= b_2$
Average number of fruits per plant	$= (b_1 \times b_2)$
∴ Average seed output for trees	$= a\ (b_1 \times b_2)$

Counts for seed output are made from the plants growing in a number of diverse localities in order to get a correct assessment. In autecology the knowledge of seed output is of great importance. It is commonly observed that annuals reproduce only once in their life, whereas the perennial shrubs and trees produce seeds usually once in a year but many times in their life time. Every species has its own range of seed output. The range of seed output may be affected by many habitat factors, both biotic and abiotic. So while taking into consideration the seed output of a particular species, various factors which affect it are also considered.

(5) **Dispersal of seeds.** The shape, size, weight and volume of seeds are important characters which govern the mode and extent of dispersal. Distribution and success in the establishment of plant species on the habitats are governed directly by the distribution of their seeds. If all the seeds scattered round the mother plants are allowed to grow, the new plants developing from them will have little chance for survival and regeneration because of over-crowding. Movement of plant populations to wider areas ensures success in the establishment of species. Thus, the study of dispersal of seeds of plants is one of the important aspects of autecology. The dispersal mechanisms and the agencies causing the dispersal of seeds and other reproductive bodies are also studied in autecology.

(6) **Viability of seeds.** Seeds have life spans of their own. They lose their power of germination after some time if stored under favourable conditions for long period. The period right from their formation up to the time when they begin to lose their germination capacity is called 'viability period'. This period varies from species to species. In some cases, the viability period is zero and the seeds are totally incapable of germination.

To test the viability, seeds are placed in petridishes on sawdust every week from the day of maturation and seedfall. The experiment is continued till the seeds do not germinate at all.

For calculating the percentage of viable seeds in a given seed sample, seeds are cut and dipped in dilute solution of TTC (tetra zolium trichloride) with a little sucrose. After 24 hours, if the embryos of dipped seeds become pink, such seeds are treated as viable.

The seeds of many crop plants remain viable for 5 to 10 years. In *Mimosa glomerata, Cassia bicapsularis* and *Astragalus massibiensis* the seeds are reported to be viable even after over one hundred years of storage. It is usually seen among in the seeds that cannot germinate immediately after formation. Viability is affected by the conditions prevailing in the particular place where the seed is stored. It has been observed that the conditions which reduce the metabolic activities are usually responsible for increasing the seeds longevity. Low temperature, low oxygen and high CO_2 contents in the atmosphere have marked effects in increasing the viability period of seeds.

(7) **Dormancy.** In some cases the viable seeds do not germinate up to a certain length of time even if the conditions for germination are favourable. This period is called dormancy period and such seeds are said to be in dormant stage and this phenomenon is known as dormancy. Dormancy may be on account of physiological immunity for germination or due to impermeability of seed coat to water and gases or due to specific light requirements or due to the presence of some germination inhibiting substances. Recently caumarin and its derivatives have been found to be present in the dormant seeds of some species. The dormancy can be broken by the following methods :

(*a*) **Mechanical methods.** When the dormancy is caused by hard seed coats that are impermeable either to water or to oxygen or both, it can be broken by abrasion, removal or puncture of seed coats. *Coriandrum* seeds are pounded mechanically before sowing which gives high percentage of germination.

(*b*) **Temperature.** The following alternating temperatures are usually given to seeds for breaking dormancy : (*i*) 0°C and 10°C, (*ii*) 30°C and 45°C and (*iii*) 0°C and 45°C. High temperature may also break dormancy, *e.g.,* in *Cassia occidentalis.*

(*c*) **Irradiation of seeds.** Irradiation of seeds to red light breaks the dormancy and increases the germination percentage in some plants. X-rays and Gamma-rays have also been found to break dormancy.

(*d*) **Chemical treatments.** Many chemicals are known to affect germination of seeds. Dormancy of seeds can be broken by dipping them in conc. H_2SO_4 for a few minutes (say 2 to 5 minutes) followed by thorough washing with water. Sometimes, it can be broken by putting soaked seeds in solution of copper sulphate or potassium permanganate or hormones.

(*e*) **Removal of Inhibitors of germination.** When the dormancy is caused by the presence of some germination inhibiting substances, it can be removed by washing the seeds in running water for varying periods of time before placing them for germination.

(8) **Seed germination and Reproductive capacity.** All the seeds may or may not germinate; some of them are inviable, some do not get proper conditions for germination and some may be destroyed by living organisms and by excess water. According to Salisbury (1942), the percentage of germinated seeds in the average seed output is called 'reproductive capacity'.

$$\text{Reproductive capacity} = \frac{\text{Average seed output of a plant} \times \text{Percentage of germinated seeds}}{100}$$

The reproductive capacity and the seedling establishment are significant for physiognomy (outward appearance) and sociological structures of species population. The process of seed germination is controlled by several factors, such as, temperature, dormancy of seeds, availability of water, concentrations of oxygen and carbon dioxide, pH value of medium and so on. In autecology of a plant species the different factors which influence the seed germination are also taken into account.

(9) **Seedling and vegetative growth.** When mature and viable seeds get favourable conditions for germination, they start germinating and after some time they establish their seedlings. Proper development and growth of seedlings are important factors for the survival of the plant. Growth performance of shoot and root in relation to climate, physiography, soil character (physical and chemical both), fire, root/shoot ratio, stomatal counts, their physiology of movements are considered. Besides, the aerial and underground productivity in various habitats and communities, water requirement (the amount of water required per gm of dry weight) are also studied. Several factors influence the growth and establishment of seedlings. Many seedlings of sal develop on moist leaf litter during rainy season but the onset of dry season even for a short period due to interruption of rains may kill many of them and unless the roots of seedlings have penetrated deep enough into the soil establishment of seedlings cannot be achieved. The aerial shoots of seedling of sal *die back* year after year but the root growth continues. Shoots regenerate every year during or before the rains. This phenomenon of "die back" continues for 20 to 25 years and only after the roots have become established in deep strata of soil with good supply of water and nutrients the plant shoots up and establishes itself. In autecological studies, thus, the knowledge about seedling growth, establishment of young seedling in a particular area and climate is essential. The intensity of solar radiations, durations and quality of light, temperature, soil conditions, water, etc. affect vegetative growth of any species. Every species in a population or community has its own requirements for the environmental conditions and has its own ecological amplitude of tolerance to an extent of fluctuation towards higher and lower sides from the optimum. Interspecific and intraspecific competitions for space, nutrients, light, water, etc. may also wipe out or delay the establishment of seedlings. Dense shade of trees and absence of sufficient light may have lethal effects on seedlings of some species. Interspecific and intraspecific competitions may be studied by growing varying number of seedlings of the same species (intraspecific) and those of associated species (interspecific) in mixed condition in a unit area and recording growth performance (mainly dry weight) of individual plants under all conditions.

POPULATION ECOLOGY

A group of individuals of a particular species occupying a definite space in which the individuals interact, intebreed and exchange genetic information is referred to as *population*. Thus one can speak of population of a bird species, population of locust species in a crop field, and so on. Population is a unit of community through which energy flows and nutrients are cycled. It is a self-regulatory system that helps in maintaining the stability of ecosystem. A population can be divided into small subgroups called *demes* or local populations. The branch of ecology which deals with the characteristics, structure and regulation of population is called ***population ecology***.

Ecological Amplitude and Law of Tolerance. A range of environmental conditions within which a species shows its characteristic growth potentiality is called *ecological amplitude* or tolerance. The geographical distribution of a species is determined by the environmental factors limiting the ecological amplitude and different ecological forms or *ecotypes* of the species. According to McMillan (1959), the species with one or few ecotypes may have narrow ecological amplitude, as for example, *Stipa spartea*, but the species represented by several ecotypes, each having its own phenotypic expression, have wide ecological amplitude, *e.g.*, *Andropogon*.

According to Shelford's (1913) *Law of Tolerance*, each environmental factor has two limits—*the maximum* and *the minimum* limits within which a species survives. They are called limits of tolerance. Maximum growth and vigour of a species is exhibited at the *optimum*. Since the environment is dynamic and it keeps on changing from time to time, it acts as a natural check on population. Physiological stress and loss of vigour begin to appear towards the limits of tolerance and the individuals of one species are unable to compete with the better adapted individuals of other species and consequently they become infrequent.

The subject of population ecology is very wide but only the following aspects of population study will be discussed here :

(*i*) Characteristics of population

(*ii*) Population structure including (*a*) analysis of population dispersal and (*b*) various types of interactions.

CHARACTERISTICS OF POPULATION

The population has the following characters :

1. Population density
2. Natality
3. Mortality
4. Population growth
5. Age, distribution of population
6. Population fluctuations.

1. Population Density

Population density refers to the size of any population in relation to some unit of space. It is expressed in terms of the number of individuals or biomass per unit area or volume, as for example, 500 teak trees per hectare; 40 lions per 100 km^2, 5 million diatoms per cubic metre of water. Population density is seldom static and it changes with time and space. Population size can be measured by several methods :

(*i*) *Abundance*—Absolute number of individuals in population.

(*ii*) *Numerical Density*—Number of individuals per unit area or volume. It is expressed when the size of individuals in the population is relatively uniform, as in mammals, insects and birds.

(*iii*) *Biomass Density*— Biomass density is expressed in terms of wet weight, dry weight, volume, and carbon and nitrogen weight per unit area or volume.

Population density can be expressed in two ways :

(*i*) **Crude Population Density.** When the density is expressed with reference to total area at a particular time.

(*ii*) **Ecological Density.** When the density is expressed with reference to total area of habitat available to the species.

The distribution between crude density and ecological density becomes important because the patterns of distribution of individuals in nature are different and individuals of some species like *Cassia tora, Oplismenus burmanni* are found more crowded in shady places than in other parts of the same area. Thus population density calculated in total area would be crude density and the densities for the shade areas and open areas separately would be ecological densities.

Population density can be calculated by the following equation :

$$D = \frac{n / a}{t}$$

where D is population density; n is the number of individuals; a is area and t is unit time. Density of human population can be obtained by dividing the total number of persons in the area by the total land area of the region. Density of population of a country can be obtained by dividing the total number of persons living in the given region by total land area of that region. Average population density in developing countries is more as compared to those in developed countries. Netherlands is smaller than India but its population density is greater (319/km^2 in Netherlands and 168/km^2 in India). Area of India is 2.5% of the world but 15% population of the world lives in India alone. The population density of India is 4% higher than that of Europe and more than 7 times that of U.S.A.

Population density is affected by a number of environmental factors, such as geographical factors, mortality, natality, emigration and immigration and socio-economic factors.

2. Natality

Natality refers to the rate of reproduction or birth per unit time. It is an expression of the production of new individuals in the population by birth, hatching, germination or fission.

Natality is calculated by the following formula :

$$\text{Birth rate or Natality } (B) = \frac{\text{Number of births per unit time}}{\text{Average population}}$$

The maximum number of births produced per individual under ideal conditions of environment is called *potential natality*. It is also called *reproductive* or *biotic potential, absolute natality* or *maximum natality*.

Natality varies from organism to organism. It depends upon the population density and environmental factors. It is a general rule that if the population density is usually low, the birth rate is also low. This is so because the chances of mating between males and females are low. If population density is unusually high, the birth rate may also be low due to poor nutrition or physiological or psychological problems related to crowding. The maximum or absolute natality is observed when the species exists under ideal ecological and genetic conditions. The actual number of births occurring under the existing environmental conditions is much less as compared to absolute natality. It is referred to as *ecological natality* or *realised natality*. It is not constant for population and may vary with the size of population as well as with the time.

3. Mortality

Mortality refers to the number of deaths per unit time.

Mortality rate = $\frac{D}{t}$ where D is the number of deaths in the time t.

Mortality can be expressed in the following two ways :

(*i*) **Minimum or Specific or Potential Mortality.** It represents the minimum of theoretical loss of individuals under ideal or non-limiting condition. Thus, even under the best conditions individuals of a population would die of old age determined by their physiological longevity. So it is constant for a population.

(*ii*) **Ecological or Realised Mortality.** It refers to the death of individuals of a population under existing environmental conditions. Since it varies with environmental conditions, it is never constant. The maximum mortality occurs at the egg, larval, seedling and old age.

Mortality is affected by a number of factors, such as, density, competition, disease, predation and environment. Death rates vary among the species and are correlated with birth rates. When the rate of natality is equal to the rate of mortality the population is stationary.

A birth-death ratio $\left(\frac{\text{Births}}{\text{deaths}} \times 100\right)$ is called *Vital index*. For a population, the survival of individuals is more important than the death. The number of births in relation to the carrying capacity of the habitat is a fundamental factor influencing the mortality rate. When more youngs are born than the habitat can support, the surplus must either die or leave the area. Because the number of survivors is more important than the number of dying individuals, mortality is better expressed as survival or as *life expectancy*. The life expectancy refers to the average number of years the members of a population have left to live.

Life Tables and Survivorship Curve. The species differ in respect of birth rates, average life span and mortality rate. When sufficient informations about a species are available, *life-table* can be formulated which provides vital statistics of mortality and life expectancy for the individuals of different age-groups in the population. In such tables age is usually represented by the subscript index *x* which is some convenient fraction of species life span, such as, years or stage of development. The life table is set upon the basis of an initial cohort or group of 100, 1000, 10,000 10,00,00 individuals and the number of living in the beginning of each successive age interval is symbolised as *lx*. Plotting these data gives a survivorship curve for a species. The number of dying individuals within each age group is denoted as *dx*. The rate of mortality during each age interval (*qx*) is commonly expressed as the percentage of the number at the beginning of the interval.

$$qx = \frac{dx}{lx} \times 100$$

Survival rate is the difference between the mortality rate and 100 per cent (*i.e.*, 100—*qx*) and is denoted by *δx*. Life expectancy (*ex*), thus, is the mean time between any specified age and the time of death of all individuals in the age group.

Types of Survivorship Curve. If it could be assumed that all members of an original population have the same capacity for survival (environmental effects for the moment are ignored), plotting the number of surviving individuals against time would produce a survivorship curve in the form of a right angle. There are three general types of survivorship curves which represent different natures of survivors in different types of population (Fig. 4.1).

(*i*) **First Type or Highly Convex Curve.** Curve *A* in the Fig. 4.1 is the characteristic of the species in which the population mortality rate is low until near the end of life span under ideal environmental conditions. Thus, all the members born at the same time live out the full physiological life span characteristic of the species and all die at about the same time. Many species of animals as deer, mountain sheep, and modern man show such curves.

(*ii*) **Second Type or Diagonal Curve.** Survivorship curve *B* in the figure 4.1 is characteristic of organisms in which rate of mortality is fairly constant at all age levels, a more or less uniform percentage decrease in the number that survives.

(*iii*) **Third Type or Highly Concave Curve.** Survivorship Curve *C* in the Fig. 4.1 is characteristic of such species in which mortality rate is high during the early stage and constant in all other age-groups. Oyster, some birds, oak trees, etc. show this type of curves.

4. Population Growth

The growth is one of the dynamic features of species population. Population size increases in a characteristic way. When the number of individuals of population is plotted on the *y*-axis and the times on the *x*-axis, a curve is obtained that indicates the trend in the growth of population size in a given time. This curve is called *population growth curve.* There are two types of growth curves :

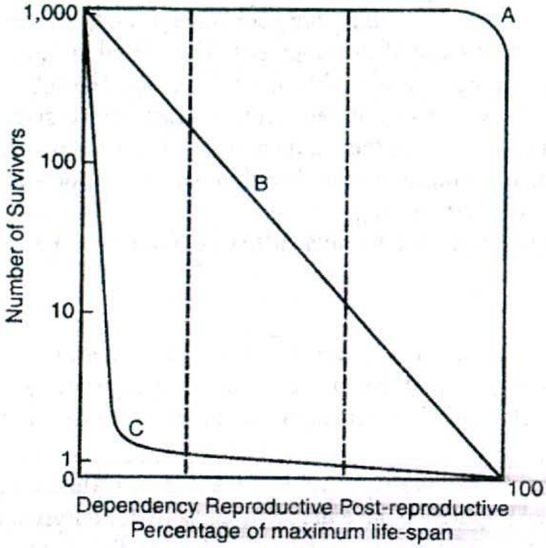

Fig. 4.1. To construct a survivorship curve, a total population of individuals, such as one thousand, is considered at age 0 (birth). At even increments of time, the total number of survivors from this thousand is plotted, and the curve is drawn. The slopes of the three basic types of survivorship curves show the following rates of changes : A—Curve for organisms living out the full physiological life span of the species (Type 1). B—Curve for organisms in which the rate of mortality is fairly constant at all age levels—a more or less uniform percentage decrease in the number that survives (Type 2). C–Curve for organisms with high mortality during the early stage in life (Type 3).

(*i*) **Sigmoid Curve.** When a few organisms are introduced in an area, the population increase is very slow in the beginning (*positive acceleration phase* or *lag phase*), in the middle phase, the population increase becomes very rapid (logarithmic phase) and finally in the last phase the population increase is slowed down (*negative acceleration phase*) until an equilibrium is attained around which the population size fluctuates according to variability of environment. The level beyond which no major increase can occur is referred to as *saturation level* or *carrying capacity*. In the last phase the new organisms are almost equal to the number of dying individuals and thus there is no increase in population size. In this way, one gets sigmoid or *S*-shaped growth curve (Fig. 4.2).

(*ii*) **J-Shaped Curve.** The second type of growth curve is J-shaped. Here in the first phase there is no increase in population size because it needs some time for adjustment in the new environment. Soon after the population is established in the new environment, it starts multiplying rapidly. This increase in population is continued till large amount of food materials exist in the habitat. After some time, due to increase in population size, food supply in the habitat becomes limited which ultimately results in decrease in population size. This will result in J-shaped growth curve rather than *S*-shaped (Fig. 4.2).

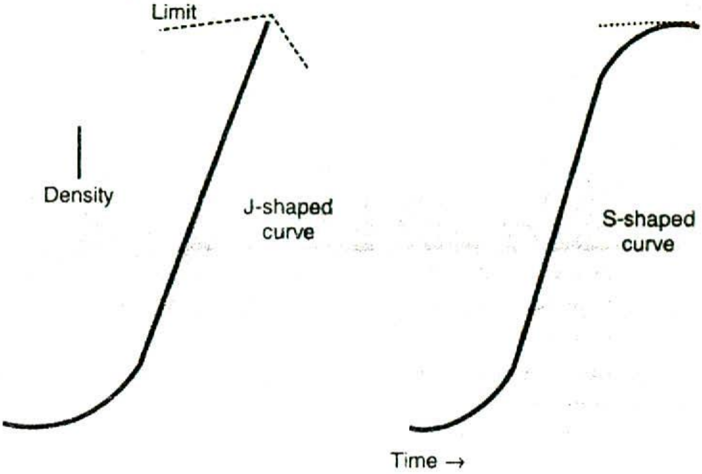

Fig. 4.2. J-Shaped and S-shaped population growth curves.

5. Age Distribution

Age distribution is an other important characteristic of population which influences natality and mortality. Mortality, usually varies with age, as chances of death are more in early and later periods of life span. Similarly, natality is restricted to certain age groups, as for example, in middle age-groups in higher animals. According to Bodenheimer (1958), the individuals of a population can be divided into *pre-reproductive, reproductive* and *post-reproductive* groups. The individuals of pre-reproductive group are young, those of reproductive group are mature and those in post-reproductive group are old.

The distribution of ages may be constant or variable. It is directly related to the growth rate of the population. Depending upon the proportion of the three age-groups, populations can be said to be *growing, mature* or *stable,* and *diminishing*. In other words, the ratio of various age groups in a population determines the reproductive status of the population. Rapidly increasing population contains a large proportion of young individuals, a *stable population* shows even distribution of individuals in reproductive age-group and a *declining population* contains a large proportion of old individuals.

Age Pyramids. Age pyramid is a model in which the numbers or proportions of individuals in various age groups at any given time are geometrically presented. In an age pyramid, the number of pre-reproductive individuals is shown at the base, that of reproductive age group in the middle and the number of post-reproductive individuals at the top. The shape of age-pyramid changes with the change in the population age distribution over a period of time (Fig. 4.3). The age pyramid indicates whether a population is expanding or stable or diminishing and accordingly three hypothetical age pyramids have been suggested. These are as follows :

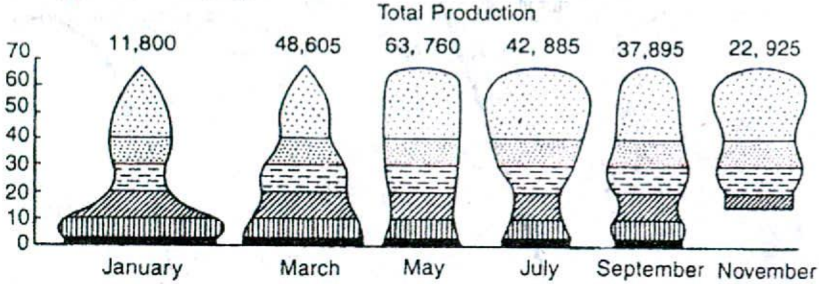

Fig. 4.3. Progressive change in age distribution of honey bees over a single season.

(*i*) **Pyramid with broad base.** This pyramid shows a high percentage of young individuals and an exponential growth of population due to high birth rate, as for example in yeast, housefly, *Paramecium* (Fig. 4.4A).

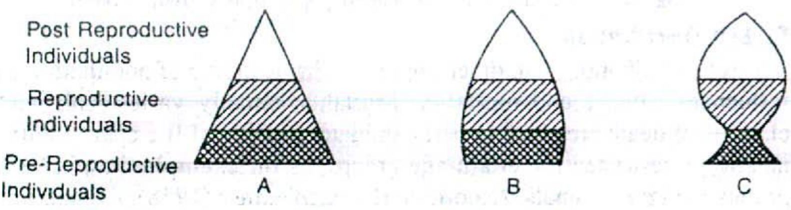

Fig. 4.4. A. Pyramid with broad base. B. Bell shaped pyramid. C. Urn-shaped or pyramid with narrow base.

(*ii*) **Bell-shaped pyramid.** This type of age pyramid shows a **stationary** or **stable** population having, more or less equal number of young and middle-aged individuals and post-reproductive individuals being the smallest in number (Fig. 4.4 B).

(*iii*) **Pyramid with narrow base.** This is an urn-shaped pyramid which shows increased numbers of middle aged and old organisms as compared to young ones in the population. It is indicative of contracting or diminishing population (Fig. 4.4 C).

6. Population Fluctuations

The size and density of natural population show a changing pattern over a period of time. This is called population fluctuation. There are three types of variations in the pattern of population change :

(*i*) **Non-fluctuating.** When the population remains static over the years, it is said to be non-fluctuating.

(*ii*) **Cyclic.** The cyclic variations may be (*i*) *seasonal,* and (*ii*) *annual.* Sometimes *seasonal changes* occur in the population and there are additions to the population at the time of maximum reproduction and losses under adverse climatic conditions. Common examples of seasonal variations are met in mosquitoes and houseflies which are abundant in particular season and so also the weeds in the field during the rainy season.

When the population of a species shows regular ups and downs over the years, it is called annual cyclic variation. It appears in the form of a sigmoid curve with regular drops in population after peaks.

(*iii*) **Irruptive.** When the change in population density does not occur at regular intervals or in response to any obvious environmental factor, it is said to be **irruptive fluctuation.** In this, there is a sudden exponential or logarithmic increase in population density in short time, followed by equally quick drop in population density due to deaths, and final return to normal level or even below that level.

Population Structure

It includes an analysis of population dispersion and various types of interactions.

Population Dispersal

Movement of individuals into and out of the population is called population dispersal. It plays important role in the geographical distribution of organisms even to the areas previously unoccupied by the members of population. Dispersal of organisms occurs for various reasons such as food, protection, prevention from overcrowding, action of wind and water, environmental factors, such as light, temperature, breeding behaviour, physiological reasons or for interchange of genetic materials between the populations.

Population dispersal occurs in nature in the following three ways :

(*i*) Emigration

(*ii*) Immigration

(*iii*) Migration.

(*i*) **Emigration.** It is one way movement of individuals out of a population. This movement is permanent and causes spread of a species to new areas. Emigration under natural condition occurs when there is over crowding in the population and is generally regarded as an adaptive behaviour that regulates the population on a particular site and prevents over-exploitation of the habitat. This type of dispersal offers new opportunity to the individuals of a population to interbreed with those of the other populations leading to more genetic heterozygosity and adaptability.

(*ii*) **Immigration.** Immigration is one way movement of individuals into a population. It leads to rise in density of population. It may result in decreased mortality among the immigrants or decreased reproductive capacity of the individuals.

(*iii*) **Migration.** Migration is two way mass movement of the entire population. It involves a periodic departure and return of the individuals of a population and occurs only in mobile organisms during unfavourable periods. It is shown by many birds, fishes and certain mammals. In most cases, migration of population occurs for food, shelter or reproduction. Through this type of movement the chances of utilization of resources in the habitats not previously occupied by any organism are great. However, during migration of population, mortality of numerous individuals may occur due to various ecological hazards, such as temperature fluctuation, scarcity of food, predation etc. Migration has certain benefits for populations as it enables wider dispersion of populations. It also avoids intraspecific competition for food, shelter, etc.

2. Interactions Among Populations

Plants and animals exhibit a wide range of relationships. Individuals of one species interact with the other individuals of the same species or with those of other species. Various types of interactions are as follows :

1. **Neutralism.** When the presence of one species appears to have no effect on the second species (*i.e.*, no interaction), it is a state of neutralism.

2. **Commensalism.** It is one-sided relationship between two species in which one species is benefited but the other is neither benefited nor harmed. Some epiphytes, as for example orchids, are the best examples. Epiphytes depend upon the other trees for support and nutrients. They manufacture their own food but do not help supporting plant in any way.

3. **Protocooperation.** It is less extreme type of interaction in which two species interact favourably with each other, though both of them are able to survive separately.

4. **Mutualism.** It is an obligatory interaction that is beneficial to both species. The term symbiosism has also been used for this relationship. Mutualism is best demonstrated in lichens. The lichen is composed of two components—alga and a fungus. The fungus supports the alga while the alga supplies food to fungus. Green *Hydra* presents another example of mutualism. This animal has green photosynthetic alga in the protective ectoderm. The alga gives off oxygen benefitting the animal which, in turn, supplies CO_2 and N_2 to the plant. Root nodules of legumes containing *Rhizobium leguminasarum* bacterium provide another example of mutualism in which there is reciprocal beneficial relationship between the root and bacteria.

5. **Amensalism.** In this type of interaction between the two species, one species is harmed or inhibited and the other is neither benefitted nor harmed by the association.

Many algae produce extracellular toxic metabolites which inhibit the growth of other algae species. *Chlorella vulgaris* (green alga) produces chlorellin which is toxic to other species of algae.

6. **Parasitism.** When two organisms live together in which one derives nourishment at the expense of the other, the condition is called parasitism. In the parasitic association, the species which provides nourishment and support is called the **host** and the one which gets support and nourishment is called the **parasite.** Several species of plants and animals form parasitic associations with other organisms. A parasite usually parasitizes a host which is larger in body size than it and ordinarily it does not kill the host, at least until it has completed its reproductive cycle.

7. **Cannibalism.** This type of interaction is limited within a species in which the bigger individuals kill and feed on the smaller ones. It is a natural method of population control.

8. **Predation.** In this type of association and interaction one species (predator) kills and feeds on second species (prey). Predation is important process in the community dynamics. Predator is always larger than the prey. From population ecology point of view predation is the action and reaction in the transfer of energy from one trophic level to the other. It represents a direct and complex interaction between two or more species of eaters and eaten.

9. **Competition.** When in the association of two or more species each species is adversely affected by the presence of the other species in respect of food, shelter, space, light, etc., this phenomenon is termed competition. It is of two types :

(*i*) **Intraspecific competition.** When competition occurs between the individuals of the same species and their requirements are common, the process is called intraspecific competition.

(*ii*) **Interspecific competition.** In this type of competition, the individuals of different species compete for common materials and conditions.

QUESTIONS

1. What is autecology? Discuss the various aspects that are important in the study of autecological life history of a three.
2. What do you mean by phenology? Discuss briefly the correlations between the phenology and the various environmental changes.
3. Write brief notes on the following :
   (*i*) Seed Dormancy (*ii*) Reproductive capacity of a species (*iii*) seed output (*iv*) Biological clock.
4. Define population. Discuss briefly the various characteristics of population.
5. Write short notes on the following:
   (*i*) Population growth (*ii*) Population dispersion and various types of interactions among population (*iii*) Population density (*iv*) Ecological amplitude.

5

ECOLOGICAL GENETICS OF POPULATION OR GENE ECOLOGY

Species differ in their environmental requirements. They also differ in respect of their tolerance to environmental fluctuations. The species occur in several morphological forms in different habitat conditions. Gote Turesson (1922), a Swedish worker conducted a series of experiments on variations within a Swedish plant species *Plantago maritina*. He collected a group of 20 or more individuals of the same species from different areas and planted them under identical environmental conditions in his experimental garden at Akark. He noted that (*i*) several intergrading forms existed within the species which differed from one another in morphological or physiological features and (*ii*) some of differences might be unstable and induced only by the environmental factors while some others might be permanent (*i.e.*, genetically fixed). These observations led him to formulate the concept of gene ecology which brought about many revolutionary changes in plant taxonomy. The population sampling and subsequent procedures that Turesson followed led him to conclude that species differ from one another morphologically, physiologically and in habitat requirements and on the basis of such studies he proposed the following classes of morphological forms within a species :

1. Ecads or Ecophenes or Habitat forms,
2. Ecotypes,
3. Ecospecies, and
4. Coenospecies.

1. Ecads or Ecophenes : These are also called epharmones or habitat forms which are environmentally induced variations. They belong to the same genetic stock or species and the variations in their morphology (in shape, size, number and reproductive capacity) are induced by the environmental influences. The variations are not fixed but temporary, somatic and reversible. If one type of ecad is transplanted into environment of another type of ecad, the differences would disappear. These morphological variations are not permanent because the genetic composition of ecads is not affected and so they are identical in their genetic behaviour and interfertile. The variants or ecophenes may differ to such an extent that they can be treated as separate species. *Euphorbia hirta* plants growing in the grassland are prostrate and profusely branched while the plants of the same species growing on the footpaths are compact, small leaved and cushioned. When these forms are grown under identical habitat conditions, their differences disappear. In *Bothriochloa pertusa* and *Dichanthium caricosum* several distinct morphlogical forms of ecads have been noted under different habitats by Pandeya (1962). In both the species there are two types of ecads : (*i*) basket form habit shown by the plants growing in protected areas, and (*ii*) saucer-shaped habit of the plants growing in over-grazed areas. Grazing causes reduction in the size of erect stem, number of spikes per raceme, number of spikelets per spike and in length and breadth of lower glumes of spikelets. In addition to these morphological variations, some physiological variations are also noticed, as for example development of anthocyanine in the leaves and early initiation of flowers.

2. Ecotypes. These are also called ecological or physiological races. The term ecotype was proposed by Turesson (1922) to the groupings of populations or ecological races or sub-species of a species in relation to different environmental or habitat conditions. These are interfertile forms or biotypes of a species which possess different genetic compositions or genotypes and arise due to mutations, hybridization and isolation. Though the different ecotypes of a species are morphologically and genetically distinct, yet because of their interfertility, they are put into one taxonomic species. Ecotypes are morphologically, physiologically and developmentally adapted to live under varying environmental conditions. Ecotype is the product of genetic response of a population to a habitat. In ecotypes adaptations are irreversible, *i.e.*, they retain their features even when planted in a neutral habitat. The differences in the ecotypes are so marked that some of them are treated as separate species by old taxonomists. Mishra and Shiva Rao (1948) found *Lindenbergia polyantha* and *L. urticaefolia* to be the ecotypes of the same species. The two ecotypes differ from each other in respect of their tolerance to high doses of lime. *L. polyantha* can tolerate high doses of lime. In another study. Ramakrishnan (1959, 60) has shown that *red* and *green populations* of *Euphorbia thymifolia* are two ecotypes. The red ecotype grows in calcium rich **(calcicol)** as well as calcium deficient soils and the green ecotype is a **calcifuge** *i.e.*, it cannot grow in calcium rich soil. The red ecotype possesses a pair of dominant alleles whereas the green type possesses a pair of recessive alleles. Ecotypes have been reported in several species of plants, such as *Euphorbia hirta, Cassia tora, Ageratum coniyoides, Cenchrus ciliaris.*

During last two decades, many investigators have studied either only a few populations or several widely separated populations and have shown that each population was an ecotype and the term is now being widely used below the level of species. Our increasing knowledge of genecology and population differentiation has shown that an ecotype may be the ecological unit but not an evolutionary unit. According to McMillan (1969), the concept of genetically based variation that is habitat correlated or population differentiation or micro evolution is valid, but ecotype as a word has limited value in its application.

Consideration of the Turesson's ecotype as a reliable ecological unit requires an assumption of environmental uniformity within climatic or altitudinal regions or habitat types. There is strong trend among evolutionary biologists to emphasize the importance of the local environment in shaping the population. Since the unit of study is the local population, it seems most appropriate if we present our information in terms of local population, rather than to imply that local population is an ecotype. If the term "ecotype" is used as equivalent to ecological race or a taxonomic sub-species, we cannot consider the ecotype to be a basic evolutionary unit. Since the evolutionary unit is the population, the use of ecotype or genetically based variation that is habitat correlated cannot contribute additional information but will create confusion. Ecotype is now used by botanists and ecologists to indicate almost any degree of genetic difference below the level of species. According to Philips (1971), the ecotype has been used as the word for an abstract concept of an ecosystem type.

Ecotype is still considered on the basis of morphological, physiological or ecological evidences. According to Davis and Heywood (1963), ecotype is based on the reaction between genotype and prevailing environment. They defined 'ecotype' as a population distinguished by morphological and physiological characteristics most frequently of a quantitative and physiological characteristics nature; inter fertile with other ecotypes of the ecospecies, but prevented from freely exchanging genes by ecological biomass.

Characteristics of Ecotypes

The characteristic features of ecotypes are mentioned below :

1. Ecotypes of a species, though genotypically distinct, are always interfertile.

2. They retain their original features when cultivated in a natural habitat.

3. Ecotypes are genetically fixed.

4. A species with wide ecological amplitude can be distinguished on the basis of morphological and physiological characters into different habitat forms or ecotypes.

5. They occur in distinct habitats.

6. Ecotypes are discrete entities with clear differences which separate one ecotype from another.

7. The differences are not due to plastic response to change in environment but are actually due to natural selection of locally adapted populations.

Formation or Origin of New Ecotypes

Now ecotypes can be produced by the following methods :

1. **Hybridization.** It is produced by the natural cross between two species. For example, when *Spartia stricta* is naturally crossed with *S. alterniflora*, the new hybrid *S. townsendii* results which eliminates both the parents from their natural habitats owing to its greater adaptability.

2. **Mutation.** Due to natural mutation and recombination small gene pools accumulate in a segregating population which make it better adapted to the particular habitat or environment. Some new ecotypes also arise by cultivation or protected growth as it eliminates competitive selection.

3. **Chromosomal changes.** Structural changes in the chromosomes such as translocation, inversions, and loss or addition of chromosome segments produce changes in genotypes and phenotypes resulting in the formation of new ecotypes. Polyploidy also leads to the formation of new ecotypes because polyploids hardly exhibit ecological tolerance as their parents.

Kinds of Ecotypes

Ecotypes have been observed in a large number of species and the cause of ecotype differention may be the latitude, altitude, light, soil, biotic interference, physiological changes, etc. According to varying environmental conditions, ecotypes may be of following types :

1. **Climatic ecotypes.** Ecotypes which are produced due to varying climatic factors as light, temperature, water and wind are called climatic ecotypes. Turesson (1930) has recorded the climatic ecotypes in *Leontodon autumnalis*.

2. **Edaphic ecotypes.** Ecotypes which are produced due to differences in edaphic or soil factors, such as soil moisture, excess or deficiency of nutrients, change of soil pH, etc. are said to be edaphic ecotypes. Misra and Rao (1948) have studied *Lindenbergia polyantha* and Ramkrishnan (1961) has studied *Euphorbia thymifolia* and recorded several edaphic ecotypes in them.

3. **Climatic-Edaphic ecotypes.** The ecotypes produced due to the influences of both climatic and edaphic factors are called climatic-edaphic ecotypes. Panday and Jayant (1970) have reported climatic-edaphic ecotypes in *Cenchrus ciliaris*.

4. **Altitudinal and latitudinal ecotypes.** These ecotypes are produced due to change in altitude and latitude. Such ecotypes are found in *Cassia tora, Anagallis arvensis, Pinus* and many other gymnosperms.

5. **Physiological ecotypes.** These ecotypes are produced due to physiological changes as in photoperiod, water absorption, nutrient uptake, etc., example in *Boutelona curtipendula,* there are two photoperiodic ecotypes—short day and long day which are morphologically alike.

Delimitation of Ecotypes

Ecotypes are not always based on morphological characters. Sometimes, single ecotype has several ecophenes which depend upon the habitats. Now a days following techniques have been applied to differentiate ecotypes:

(*i*) **Morphological features.** In this case morphological or physiological features of several individuals are studied at random in different populations of a species and one or few characters are considered and the results obtained are shown in the graph. Unimodal curve shows homogenous population, bimodal, trimodal or multimodal curves show two, three and many ecotypes in the population respectively.

(*ii*) **Anderson's Scatter Diagrams.** This was devised by Anderson (1940) to delimit ecotypes. For this some measurable characters are taken into consideration. One type of character (for example, leaf length) is plotted on one axis of the graph and other character (for example, leaf breadth) is plotted on another axis. In this way large number of characters are taken from different localities.

(*iii*) **Cytological behaviour.** In this case karyotypes and their behaviour are observed in different forms. The differences in cytological behaviour show the existence of distinct ecotypes.

(*iv*) **Transplantation experiment.** In this experiment plants from all the different localities are grown under uniform environmental conditions and their morpho-physiological characters are compared with plants growing in natural habitat. If the characteristic features are not changed in the neutral area, the existence of particular ecotypes is confirmed.

(*v*) **Breeding experiments.** In this case, crossing is done between different forms of variable nature followed by self-fertilization the determine the characteristic features of variable forms. If the characteristic features show segregation in the offsprings, the presence of distinct ecotypes can be proved.

Significance of Ecotypes

1. Cultivation of economically important plants has been made possible in different habitats.

2. New ecotypes of a species enable it to be adapted to climatically and edaphically different places.

3. Ecotypes help the species to extend its ecological range and spread to new areas.

4. Morphological variations can be marked in the species growing on varying habitats which lead to evolution.

5. **Ecospecies.** Ecospecies and coenospecies are two parallel terms. Gregor (1939) defined ecospecies and coenospecies purely on the basis of fertility-sterility criteria, eliminating any specific demand for morphological, physiological or cytological differences. According to him, ecospecies is a unit of gene ecological classification. An ecospecies has one or more ecotypes which are interfertile but ecotypes of one ecospecies do not produce offspring when crossed with the ecotypes of other ecospecies.

6. **Coenospecies.** Different ecospecies which can undergo occasional crossing but do not produce viable offspring are collectively brought under coenospecies. In other words, populations incapable of exchanging genes with other populations of the same species are referred to as coenospecies.

QUESTIONS

1. What is ecotype? Describe the origin and development of ecotypes.
2. What are characteristic features of ecotype? How is new ecotype evolved?
3. What are the different types of ecotype? Describe with suitable examples. Gives some Indian examples of ecotypes.
4. What is the difference between ecotypes and ecophenes? What are the significances of ecotypes?

6

SYNECOLOGY OR STUDY OF COMMUNITIES

No plant or animal lives as isolated individual. Plants and animals generally prefer to live in groups or colonies. Different plants and animals living in a habitat constitute a biotic community. When only assemblage of plants in a habitat is considered, it is called *plant community*. Similarly, assemblage of animals in a habitat is called *animal community*. In any biological organization plants and animals are very closely related and interdependent and at a particular place plants and animals share the same set of conditions and same environment. In view of these facts, modern biologists prefer use of biotic community to plant community or animal community. The study of the relationships of plants and animals making up a natural community is termed as ***community ecology*** or ***synecology***.

The basic unit of vegetation is called plant community or a plant association. The communities are not the random mixtures of species. The species living together in groups exhibit various degrees of adjustment among themselves and with their physical habitats as well. Each community consists of a set of many different species which persist year after year. In a community, each plant species is represented by innumerable individuals. A group of individuals of the same species is commonly known as *population*. Thus a population is a part of community and populations of different species may be intermingled in a community. Oosting defines community as "an aggregation of living organisms having mutual relationship among themselves and to the environment." In modern books of ecology, plant community is defined as *'uniform floristic composition.'* Earlier Gleason (1939) in his individualistic concept of plant association suggested that an association is a complex of slight irregularities, all of which blend into an entirety of apparent homogeneity. It is uniform either in space or in time and possesses definite limits of area only to a reasonable extent.

Pondeyar (1960, 1961) has discussed this subject and suggested that an association is a temporary phenomenon which is continuous in space and with slight irregularities, all of which blend into an entirety of apparent abstract homogeneity. According to him, the association is not a final vegetation but an assemblage of plants of any status. Misra and Puri (1954) are of the opinion that Clements' original concept which defined "community as any unit of vegetation, whether developmental or climax in status", should be accepted as such and they used the term *association* for *climatic climax*. According to them, the climatic climax community is in, complete equilibrium not only with climate but also with the whole complex of environment.

Community Composition

The following points characterise the community :

(1) **Species diversity.** The biotic community is a natural assemblage of a large number of plant and animal species in an area. Actually it is a part of a larger whole ecosystem in which living and non-living components interact and bring about circulation, transformation and accumulation of energy and matter.

Because in any particular habitat there is no considerable variation in environmental conditions, the plants growing together in a community show unique uniformity in their behaviour. Vegetation, therefore, is reflection of a climate and, in general, widely separated areas having similar climate have similar aspects of landscape.

Some community areas have limits but more often the community boundaries are hard to define. A clearly distinguished area or a type of area with uniform habitat conditions and supporting characteristic type of vegetation is termed "biotope".

Each species of community has got definite range of tolerance towards the physical and biological environmental conditions of the habitat. The range of environment a species can tolerate is called its **ecological amplitude.** The nature of community of a particular habitat is determined by the species contents, ecological amplitudes of the species and physical and biotic influences prevailing in the locale of community.

(2) **Coexistence.** Species occurring in the particular habitat do not live in complete isolation as pure cultures, but they coexist in mutual adjustment. The coexisting populations are interrelated and they show some sorts of interaction. The relationships, between coexisting species may be obligatory in one direction or in both. The trees in a forest community can live just as good as without shrubs and herbs which grow under them. This relationship is obligatory in one direction only. The relationship between plants and animals which pollinate them is obligatory in both directions.

The nature of interaction between two coexisting species may fall into one of the following types :

- (*i*) **Exploitation.** In this, one species lives at the expense of another.
- (*ii*) **Mutualism.** In this, two or more coexisting populations benefit from the relationship but none suffers.

(*iii*) **Competition.** In this, two populations may compete for same resources of the habitat.

(*iv*) **Neutralism.** In this, two populations may be quite independent and neither population affects the other.

(3) **Interdependency.** All the members of a community have ability to live under the conditions of the habitat and they are interdependent upon one another to some extent. It is called *dependency.* Thallophytes, mosses, ferns and many shade loving herbs that are found on the forest floor are dependent on the forest trees because trees provide shadow and moist conditions. If the trees of forest are removed, the ground vegetation may disappear. Similarly, the fungi and saprophytes found in the forest depend upon the roots of plants and on the rich humus and some fungi form mycorrhizal associations with the plant roots. Some sort of relationship also exists between plants and the insects and other animals which pollinate them.

(4) **Species dominance.** Not all the species of a community are found in adundance. Only a few species are found in abundance, either in number or in biomass (living weight) while the majority are rare. The common species which are abundant and contain maximum biomass are considered to be **dominants**. Dominant individuals influence the associated individuals. In the forest, tallest trees, for example, influence the understorey plants and ground vegetation not only by decreasing the intensity of light reaching the forest floor and increasing the moisture content of air but also by changing the soil structure and its chemical composition. The dominance in the community may be the result of co-action between two or more species. Different communities are generally recognised and named on the basis of dominant species occurring in them.

(5) **Stratification.** In a plant community, the plants, which have some sort of relationship among themselves, may be trees, shrubs, herbs mosses, lichens and thallophytes. These plants form, more or less, distinct strata or layers or storeys on vertical as well as in horizontal planes. This is characteristically known as *stratification.* The individuals of different layers represent different "*life forms*". Each layer of community may sometimes include individuals of different morphological classes, as for example, the top layer or canopy of forest may be formed by tallest trees and lianes (woody climbers). In order to overcome this objection, plants belonging to different morphological classes are put in 'sinusiae' (singular—sinusia), as for example, trees are put in sinusia of trees, epiphytes are put in sinusia of epiphytes, and so on.

In grassland, there are essentially three strata : (1) the root and rhizome layer, (2) the ground layer, and (3) herbaceous layer.

In forest vegetation, the stratification reaches its greatest complexity. As shown in Fig. 6.1, five vertical subdivisions (units of homogeneous life forms and ecological relations) may be present—(1) *subterranean zone,*

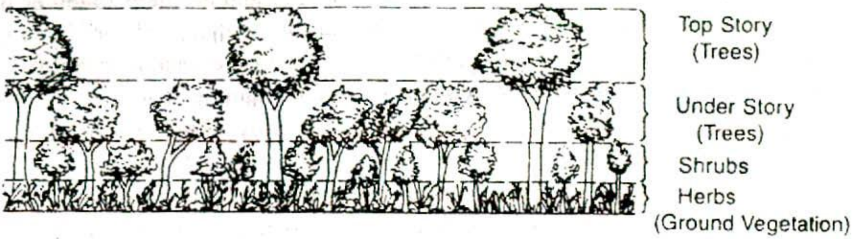

Fig. 6.1. A forest showing stratification of the plants.

(2) *forest floor,* (3) *ground vegetation* nearly extending upto a metre or so, (4) *understorey tree* and *shrub layer* extending to the height of one to five metres and (5) *tree layer* or *top storey* extending to the extent of 5 to 15 metres in most of the forests, but sometimes it may extend upto 25-30 m in the coniferous forests and to about 40 or 50 m in rain forests. In *Sequoia* forest, the upper canopy may surpass 100 m. The different strata of plant community are determined by light penetration; the maximum light is available to plants of top storey and the minimum light reaches the ground vegetation. It is evident from Fig. 6.2.

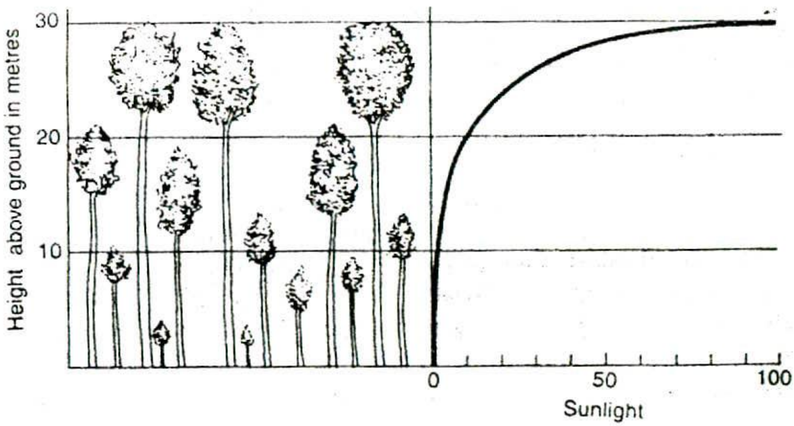

Fig. 6.2. Stratification of a forest and height levels.

(6) **Succession.** Interacting populations of community are characterized by continuous death and replacement and usually by immigration and emigation (one way movement from home range to other habitat) of their individuals. In this way, composition and shape of community remains in changing state. The changes in the community go on taking place until a complete balance is established between community and environment. This is called **succession**. At complete equilibrium state a stable community is established which is called ***climax community***. In the climax community very little or no change in the shape can be anticipated over a long period of time.

A mixture of species which live in a habitat and are held together by common ecological tolerances form a community. As indicated earlier, some communities have sharply defined limits and they are characterized by a, more or less, definite species contents, as for example, community of a pond or a small island or old field. Thus, they show *discontinuous* vegetational patterns.

There are, however, several instances of community types which do not have well defined limits and one community generally merges with another community. The species occurring in a community are not bound together into group of associates; and they respond independently to the physical and biotic factors of the environment. Thus with the change in the environment, the composition of community also tends to change. The sequence of communities showing a gradual change in composition is called ***continuum*** (Curtis 1959). Community in such a gradient can be recognized as a discrete point with uniform floristic composition in the *continuum*.

As regards the composition of community, there are two opposing philosophies :

(*i*) Organismic view, (*ii*) Individualistic view.

The **organismic view** was advanced by Clements (1916) and is still supported by his school of ecology. According to this view, the community is a sort of *"super organism"*, the highest stage in the organisation of living world, rising from cell to tissue, organs, organ-systems, species, population and to community. The community is regarded as super organism because it grows, adjusts under some circumstances, reproduces itself, and functionally represents higher level of integration than individual plants and animals that make it up. The community acts as unit in the succession.

The **individualistic concept** was first advanced by H.A. Gleason (1926) and further supported by Whittaker (1951, 1952, 1956), Curtis (1958), McIntosh (1959) and several other ecologists. This approach emphasizes that no community necessarily reaches any prescribed composition or steady state. In this, species has been recognized as essential unit because it is only the species, and not the community, which is directly involved in inter-relationships and distribution. The species directly respond to the environmental conditions independently. They are not bound together in associates. The plants and animals exhibit a gradient or *continuum* from one extreme of environmental conditions to the other. In this approach of community composition the community is regarded as a continuous variable.

Ecotone. The transition or marginal zone between two major communities presenting a situation of special ecological interest is called an *ecotone* or *tension zone*. The transition zone between grassland and forest or the intermediate zone between any two major land or aquatic communities are the examples of ecotone. Strictly speaking, a transition zone is an ecotone only if tension exists between the bordering communities. The ecotone is colonized by the species that are commonly found in the communities on both the sides, as well as by some versatile species of plants and animals. As a rule, the ecotone contains more species and often denser populations than the bordering communities. This is known as *'principle of edges'*. This edge effect is chiefly due to wider range of suitable environmental conditions.

PHYSIOGNOMY

Life-form Classes and Biological Spectrum

The climate determines the types of plants that can exist in each region. General appearance of vegetation is referred to as **physiognomy.** It constitutes general stature, shape and life-forms of the species comprising the vegetation and actually the classification of vegetation types has been done on the basis of physiognomy. The species of a community can be grouped into several life-forms on the basis of general appearance and growth. The life-forms of the vegetation are to a certain extent indicators of the climate. This idea has been extensively developed by a Danish botanist Raunkiaer (1934). He considered that it is the unfavourable environmental condition which exerts a major control over the growth form and he stressed the significance of the adaptations of buds and shoot tips for overcoming adverse temperatues and survival in drought. A classification of plants on the basis of the types and kinds of perennating organs seems to be natural. Raunkiaer called the kinds and types of these organs as **life-forms.** Raunkiaer employed three guiding rules in the selection of life-form characteristics :

(1) The character must be structural and essential and must represent important morphological adaptation.

(2) The character must be sufficiently clear that one can easily see in nature.

(3) All the life-forms employed must be of such nature as could constitute a homologous system and represent a single point of view or aspect of plants and thus enable a comparative statistical treatment of flora of different communities. On the basis of these principles, he recognised five life-form groups. These groups are as follows :

(1) Phanerophytes
(2) Chamaephytes
(3) Hemicryptophytes
(4) Cryptophytes
(5) Therophytes

Cryptogams are not included in this system :

(1) **Phanerophytes.** In these, the perennating buds are located on the twigs and branches and are exposed to the atmosphere during unfavourable periods. Plants are mostly woody (trees and shrubs), although lianas, epiphytes and some large perennial herbs can be described under this group.

According to their heights, phanerophytes are divided into the following classes :

(*i*) Megaphanerophytes; Perennial parts including buds are more than 30 metres in height.

(*ii*) Mesophanerophytes; Between 8 and 30 metres height.

(*iii*) Microphanerophytes; Between 2 and 8 metres height.

(*iv*) Nanophanerophytes; Under 2 metres and over 25 cms tall.

The above height classes are further divided according to the conditions whether the meristematic tissue of buds are protected by bud scales or they are naked and whether the plants are evergreen or deciduous.

(2) **Chamaephytes.** Buds or shoot apices are situated on shoots that lie on or near the ground surface. Plants of this class are less than 25 cm in height but their perennating buds are found definitely above the soil surface. During the unfavourable seasons, the buds are protected by the dead fallen leaves and on higher altitudes they are protected by snow. Chamaephytes are divided into the following classes :

(*i*) **Subfructicose chamaephytes.** Buds are protected by dead plant remains. Examples—Caryophyllaceae, Labiatae, Leguminosae, etc.

(*ii*) **Passive chamaephytes.** Shoots lie on the ground surface. Examples—*Saxifraga, Polygonum, Sedum,* etc.

(*iii*) **Active chamaephytes.** Buds lie on the ground and are protected by snow under the unfavourable conditions. Example—*Vinca.*

(*iv*) **Cushion chamaephytes.** They represent transition stage from chamaephytes to hemicryptophytes. In this group the shoots are closely packed, for example, *Azorella.*

(3) **Hemicryptophytes.** They are found on the soil surface and buds and shoots are protected by soil and dead leaves. They are herbaceous and spread on the surface horizontally as runners. The group is divided into protohemicryptophytes, partial rosette plants, and rosette plants.

(4) **Cryptophytes.** In this group, the buds and shoots of plants are underground. Reserved food material is stored in the subterranean perennating organs. The class is divided into the following categories :

(*i*) Geophytes

(*ii*) Helophytes

(*iii*) Hydrophytes

(*i*) **Geophytes.** They are land plants with subterranean perennating buds. They are of following types :

(I) Rhizome geophytes.

(II) Stem tuber geophytes,

(III) Bulb geophytes,

(IV) Root tuber geophytes,

(V) Root geophytes.

(*ii*) **Helophytes.** These are the plants of water saturated soil. The leaves and flowers emerge above the ground but the rhizomes are subterranean.

(*iii*) **Hydrophytes.** They are water plants, for example—*Eichhornia, Nelumbium,* etc.

(5) **Therophytes.** This group includes those annual summer plants which survive under unfavourable seasons in the form of seeds. In summer, all the pats of plants die except seeds and fruits. Thus, the perennating bud is actually the embryo of the seed.

Braun Blanquet's Classification

Braun Blanquet (1951) modified classification of Raunkiaer and proposed a new scheme of classification of vegetation. The scheme is as follows :

1. **Phytoplankton** (Microscopic floating plants)
   (*a*) Aeroplankton (float in air)
   (*b*) Hydroplankton (float in water)
   (*c*) Cryoplankton (float in ice and snow)
2. **Phytoedaphon** (Microscopic soil flora)
   (*a*) Aerophytobionts (aerobic) } Bacteria
   (*b*) Anaerophytobionts (anaerobic) } Bacteria
3. **Endophytes**
   (*a*) Endoxylophytes (Parasites of plants)
   (*b*) Endolithophytes (Algae, Fungi and Lichens)
   (*c*) Endozoophytes (Pathogens on animals)
4. **Therophytes**
   (*a*) Thallotherophytes (Myxomycetes and moulds)
   (*b*) Bryotherophytes (Liverworts and mosses)
   (c) Pteridotherophytes (Vascular cryptogams)
   (*d*) Entherophytes (annual seedplants) which may be creepers (climbers or erect).
5. **Hydrophytes** (All water plants except planktonic forms)
6. **Geophytes** (Earth plants)
   (*a*) Geophyta mycetosa (Root and tuber inhabiting fungi)
   (*b*) Geophyta parasitica (*e.g., Rafflesia,* a root parasite)
   (*c*) Eugeophytes with bulb, rhizome and root tubers.
7. **Hemicryptophytes** (Some thalloid algae, fungi, lichens and rooted creepers, climbers and Rosette plants).
8. **Chamaephytes** (Mosses, lichens, leaf succulents, cushion plants, hard grasses, semishrubs and trailing shrubs).
9. **Phanerophytes** (Succulent cacti, herbs, liana plants).
10. **Epiphyta arboriela** (Tree epiphyte).

Biological Spectrum or Phytoclimatic Spectrum

Raunkiaer's system is unitary being based completely on the position and protection of perennating buds during unfavourable seasons. The characters are structural, essential and adaptive. Further more, they provide simple basis for statistical treatment. The array of percentages of life-form classes of a flora of any area composing any floristic community is called the *biological spectrum* or *phytoclimatic spectrum*. Since each life-form class is related to the environment, the biological spectrum is direct indicator of its environment. In biological spectrum, the life-form classes are represented by their percentages. Raunkiaer prepared a normal spectrum based on sampling of world flora using one thousand entities. The normal spectrum provides a base line from which the departure of percentages of any class in any given flora can be ascertained. The normal spectrum has :

Phanerophytes 46%

Chamaephytes 9%

Hemicryptophytes 26%

Cryptophytes 6%

Therophytes 13%

Generally, the biological spectra are worked out and compared with Raunkiaer's normal spectrum.

The percentage of phanerophytes in different floras ranges from zero to over 74% in the tropical rain forest. The higher percentage of phanerophytes is indicative of phanerophytic climate. The higher percentage of therophytes (above 40%) indicates therophytic climate (desert). High percentage of chamaephytes (above 50%) indicates an extremely cold climate. High percentage of hemicryptophytes in temperate forest vegetation indicates the conditions favourable for the development of extensive grassland. Geophytes (cryptophytes) are abundant in the regions of mediterranean climate and in the broad leaf deciduous forest. The biological spectra of different areas differ from one another and there is no base line for comparison.

There are certain limitations to usefulness of biological spectrum as are indicative of climatic condition, because at certain places it does not indicate the environmental conditions, for example, therophytes are abundant in Indogangetic planes where phanerophytic vegetation should actually be dominant. Biotic agencies are the chief causes for changing the biological spectrum in a given floristic zone. Thus comparison of biological spectrum with normal spectrum may sometimes create conclusions and may also lead to wrong conclusions.

As the leaves are essential part and are very much affected by climatic conditions, their shapes and sizes have been taken as important criteria in further classification of different life-forms. Raunkiaer used leaf size as important character in classification, and classified plants into the following leaf sizes classes :

Leaf size classes	*Leaf size*
1. Leptophyll	Upto 25 sq mm in area.
2. Nanophyll	From 25 to 225 sq mm in area, the upper limit being 9 × 25 sq mm.
3. Microphyll	Area from 225 to 2025 sq mm (20.25 sq cm or $9^2 \times 25$ sq mm).
4. Mesophyll	Area from 2025×18,225 sq mm (182.25 sq cm or $9^3 \times 25$ sq mm).
5. Macrophyll	Area from 18,225 to 164.025 sq mm (1,640.25 sq cm, or $9^4 \times 25$sq mm).
6. Megaphyll	Larger than macrophylls, area over 1,640.25 sq cm.

EVOLUTION OF PLANT COMMUNITY OR COMMUNITY DYNAMICS

Evolution of plant community on a bare area is quite a prolonged process. This involves a number of stages. Each stage is characterised by particular assemblage of plant populations and dominants. It is difficult to recognise these stages because of the fact that the process of community evolution is continuous. However, these stages can be defined on the basis of their characteristic vegetation. Evolution of plant community involves the following important steps and processes :

(1) **Nudation.** The development of bare areas is initial prerequisite. The naked areas develop either by emersion, submergence, glacial recession, erosion, deposits and climatic change or by biotic agencies.

(2) **Migration including initial colonisation.** When the area becomes bare some plants from the nearby localities move into it in the form of germules, propagules or migrules (structures or off-springs reaching from different places). This process is known as migration. Migration starts when germules leave their parent areas and terminates when they reach the final resting place. The movement between these two places may complete in one or two steps. It is only by migration, plants from an area are brought into new areas. Several agencies help in the migration of plants to new areas. They are wind, water, animals, man, glacier, etc. Migrules may jump into the new area from all the surrounding localities or from one side only.

(3) **Ecesis.** It is a process of establishment of immigrants. When the migrants enter a new area, they germinate, grow and reproduce there. It is not necessary that all the migrules reaching the new area must stabilize. The stabilization depends greatly on the conditions prevailing in that area. The first plants growing in the new area are known as *pioneer colonisers*. The germination may be affected by a number of external and internal factors. Dormancy may be a barrier in the germination. Viviparous germination is helpful in the establishment of halophytes in the saline marshy places as the saline habitat has marked inhibiting effect on germination.

(4) **Aggregation of germules.** In the beginning, pioneer plants may be present in very small number and they grow far from one another. These plants produce reproductive structures which will be dispersed in the open areas around them and after germination they form their family groups.

In the course of evolution, more new migrules reach the open areas and become stabilized there. This grouping together of colonising individuals in bare area after migration is termed as *aggregation*. Aggregation may be of two types :

(*i*) **Simple aggregation.** In this, the germules are aggregated in a group around the parent. This is independent of immigration. It increases the number of individuals of only one species, *e.g.*, *Gloeocapsa, Tetraspora*. Falling down of fruits and seeds of the plant just below it is also aggregation.

(*ii*) **Mixed aggregation.** When the individuals from the family groups migrate away and some more new immigrants are brought by some means into the area under colonisation, it is called mixed aggregation.

(5) **Evolution of community relationships.** When the bare areas become occupied by the individuals of colonizing species, they become related with one another. The relationship may be of the following three types :

(*i*) **Exploitation.** In this, one species lives at the expense of another.

(*ii*) **Mutualism.** In this, one or both species benefit from the relationship but none suffers.

(*iii*) **Co-existence.** In this, the species live together in some measures of actual or potential competition for same necessities, such as light, moisture, space and nutrients.

Competition starts among the constituents of vegetation when the supply is in adequate to meet full requirements of all. Competition may be interspecific or intergeneric. It increases with the increase in the number of individuals in the populations. If the populations over the entire community range are habitually at levels producing interspecific competition, coexistence will be possible only for species best adapted to some recurring variants of the ecological pattern of the community. Competition is, perhaps, most acute in the early stages of growth when mortality is highest. Between individuals of the same species an equilibrium may be established so that over a wide range of population density the total productivity is very similar. The reactions vary greatly between the individuals of different species. In perennials, the mode of growth and rate of potential spread play important role in competition. Competition continues until the vegetation is fully established.

(6) **Invasion.** In the process of colonization, germules of aggressive and more adapted plants reach the adjacent area from time to time. There they grow and become established. This process is termed as *invasion* and the new aggressive and more adapted organisms are called *invaders*. Invasion may be intermittent (periodic) or continuous. The invaders establish themselves in the new area either temporarily (partial invasion) or permanently

(permanent invasion). New invaders may come either from the areas adjacent to the locality under colonisation or they come from the places in the same locality. There are several barriers to check the invasions. Some of them are as follows :

(*i*) Topographic barriers : mountains, valleys, slopes, etc.

(*ii*) Physical barriers : oceans, lakes, rivers, deserts, etc.

(*iii*) Biotic barriers : man, animals, insects, etc.

(7) **Reaction.** This essentially involves the changes that are brought in the habitat conditions by the plants themselves. This is the effect of interactions between vegetation and habitat. Plants modify the environment particularly in two ways :

(*i*) by changing the nature and reaction of soil, and

(*ii*) by modifying the climate.

Acute competition among developing plant communities causes the disappearance of many individuals. The dead remains of colonisers are added to the soil in the form of humus. Humus changes the soil structure to a considerable extent. It also increases the water holding capacity, aeration and mineral contents of the soil. Shadow of the plants checks the rise of temperature and increases the humidity of the air.

Reaction is continuous process. This leads to the development of such conditions as are less favourable for the growth of previous colonising individuals and more favourable to the new invaders. In this way reaction plays important role in the replacement of pre-existing plants by the new invaders.

(8) **Stabilization.** Continuous competition and reaction bring about several marked changes in the environment and consequently introduce gradual change in the structure of vegetation. After a long time, some such individuals come and dominate in the area as are least affected with the new changes in the habitat. Climate at this stage plays principal role in determining the nature of community. This process is called stabilization.

(9) **Climax.** The final stage of vegetation development after the stabilization is called climax stage. The dominant species of climax community are nearly in complete harmony with its habitat and environment. Climax community is nearly stable and will not change so long as the climate and physiography remain the same. However, complete climax is impossible because the community and environment both are changing, *i.e.*, they are in dynamic state.

CLASSIFICATION OF COMMUNITY

Plant communities have been classified in several ways according to particular need or viewpoints. The following criteria have been widely used in the classification of communities :

(1) Physiognomy, (2) Habitat, (3) Species composition and dominance.

Physiognomy refers to the general appearance of plant community. Major plant communities of large area are classified into component communities on the basis of physiognomy. Component communities recognized on the basis of physiognomy are named after the dominant life forms as for example, forest, grass land, desert community, etc.

Major communities are sometimes divided into smaller segments on the basis of habitat, mainly on the basis of water contents in the habitats. Sometime, five different types of component communities can be delineated in a major community on the habitat basis :

(1) Wet land community, (2) Wet-mesic community, (3) Mesophytic community, (4) Dry-mesic community, and (5) Dry land community.

Major plant communities are often divided into smaller divisions on the basis of species composition and dominance. Such a classification requires the knowledge of species content of the community, frequency (the regularity with which a species is distributed throughout community), dominance, and fidelity (faithfulness of species to their community). If two areas have similar communities, the communities are named after dominant organisms or those that show high frequency, *e.g., Betula-Rhododendron-Magnolia* association, Oak-hickory forest.

Clements recognized dynamic nature of community and he developed floristic classification with emphasis on succession, dominance, constancy, and diagnostic species. According to Clements, vegetation can be analysed into the following classificatory units in descending sequence.

1. **Formation.** According to Clements, the major unit of vegetation is plant formation. Plant formation is a great vegetational unit in a region determined by several dominant growth forms, as for example, the forests which are characterised by trees. Plant formation is a product of macroclimate and is controlled and delimited by climate alone. In other words, 'formation occurs in a natural area of essential climatic unity' (Weaver and Clements, 1938). Whittaker is of the opinion that plant formations are not distinct or concrete vegetational units determined solely by climate, but they are abstract groupings of communities of similar physiognomy (outward appearance of community) and environmental relations. The formation, according to Clements (1938), is a complex organism and as such it arises, grows, matures and reproduces. Mature vegetational unit which shows no sign of change in its climatic region is termed as *climax community* and changing vegetational units are termed as *seral communities.*

Dansereau (1958) considers the following basic formation types :

(*i*) **Forests.** These are characterised by trees. The forests may be evergreen and deciducus, high and low (mostly above 8 metres) tangled with lianas, heavy with epiphytes or sparse, long lived and some rather short lived. They may harbour little undergrowth or a dense carpet of mosses. Forests of 6 types have been recognized by Dansereau (1958).

These are (*a*) tropical rain forest, (*b*) temperate rain forest, (*c*) tropical deciduous forest, (*d*) evergreen deciduous forest, (*e*) needle leaf evergreen forest, (*f*) evergeen hard-woods.

(*ii*) **Woodland.** It is open stand of trees which are as tall as trees growing in forest but scattered rather than clumped.

(*iii*) **Savanna.** It contains low, branched, often flat topped small trees (less than 10 m in height) and many other woody plants scattered regularly or assembled in small groves. The intervening spaces are often occupied by seasonal grasses (in tropics).

(*iv*) **Scrub.** It is an essentially continuous stand of medium sized, compact growing, busy plants separated by bare ground or herbaceous patches.

(*v*) **Prairie.** It is continuous stand of tall dense grasses which are more than 50 cm high. They are usually seasonal in distribution. Besides grasses, very few shrubs may be present there.

(*vi*) **Meadow.** It is continuous stand of herbaceous plants, the majority of them being graminoids. Meadows are devoid of woody plants.

(*vii*) **Steppe.** It is an open stand containing bunch of grasses interspersed with low shrubs. Steppe and scrubs or steppe and meadow or even prairie differ each other in respect to the plant coverage.

(*viii*) **Desert.** It is characterised by extremely low permanent coverage. The perennial vegetation (mostly woody or succulent and evergreen) is very sparse and during rainy season the ephemerals may cover the area.

(*ix*) **Tundra.** It consists of a very low woody vegetation, trailing shrubs and cushion plants intermingled with mosses.

(*x*) **Crusts.** These are formed by algae, fungi, lichens on the rocky surface or soils.

2. **Association.** Every climax formation consists of two or more subdivisions which are known as associations, each being marked by more than one dominant species that are peculiar to it. Association is regional vegetation in the formation. It is climax of subclimate within the general climate of the formation. Each association is similar throughout its extent in physiognomy, in its ecological structure and in general floristic composition (Weaver and Clements, 1938). Example of association is Oak-Beech association. Developing counterpart of association is called ***associes***. Now the association concept has fallen in disuse and in its place community continuum is gaining popularity. The vegetation is continuous, though differing from place to place. It cannot be categorised into well defined units because it is in changing state. Whittaker (1951, 56) asserts that association is not a concrete natural community. L.E. Braun too criticised association concept in a symposium organised by Ecological Society of America in August, 1956. The main points of objections are :

(*i*) That the communities do not have definite limits but intergrade with one another.

(*ii*) That the species which seem to characterise them may exten other communities, although, probably in different proportions.

(*iii*) That two communities are not exactly alike.

(*iv*) That the vegetation (leaving aside only those places where hab change abruptly) is continuous, though differing from place to place

3. **Faciations.** Each association which fundamentally includes m dominant species consists of two or more subunits. These are ca ***faciations***. Each faciation may be dominated by two or more dominants, the total number of dominants in faciation will be lesser than tha *association*. Seral or developing counterpart of faciation is termed as ***fa*** Another local variation of the association is *location* which va particularly in the composition of subdominants and influence.

4. **Consociation.** When there is only one dominant in climax commu that is known as consociation. Consociations are smaller unit communi whose single dominants still have the life-forms characterising the format Such **eca** (vegetational units) are modified greatly by edaphic conditi example—Oak or Beech consociation in Oak—Beech association. developing counterpart of consociation dominated by single specie termed as ***consocies***.

5. **Societies.** Association and consociations can further be analy into several minor communities which are under the direct influence of l variations of habitat. These minor communities are dominated by on more species other than the dominants of associations and consociati These smaller units are called **societies**. The dominants of societies sub-dominants of higher **econ**. Society thus shows dominance wi dominance whose dominant species is (or are) subordinate when we cons consociation as a whole. Developing societies are called *socies*. If so have got two or more invading species without evident association, t may be called colonies.

6. **Clans.** In each society there may be found two or more smal units. These are called **clans**. Each clan is a small aggregation of single very locally and overwhelmingly dominant species. The seral equivalen the family derived from multiplication and gregarious growth of sin immigrant.

STUDY OF PLANT COMMUNITY STRUCTURE

The special field of synecology which is concerned with the struct and classification of plant community is known as ***phytosociology***. study of structure and composition of plant communities has been develo largely in Europe and Zurich-Montpether school of vegetational anal led by J. Braun-Blanquet who has outlined several methods grouping th into phytosociology. Two sets of characters, *viz., analytical* and *synth* are studied in a community at the same time.

Analytical Characters

According to Hanson (1950) and Braun Blanquet (1932), analytical characteristics are those features of community which can be observed or measured directly in each stand. They include kinds and number of species, distribution of individual, species vigour, form, number of individuals, height of plants, area volume, growth rate and periodicity, etc. There are two different aspects of vegetational analysis—namely ***quantitative*** characters which can be measured more readily than the others, and ***qualitative*** characters (which are described and not measured).

Synthetic Characters

Those aspects of community which are based on analytical characteristics and utilise data obtained in the analysis of a number of stands.

A. Qualitative Structures of Plant Community

The qualitative structure and composition of plant community can be described on the basis of visual observations without any special sampling and measurement. In the qualitative characteristics floristic enumeration (species content), stratification, aspection, sociability, interspecific associations, life-forms and biological spectrum, etc. are studied in the field.

1. **Floristic composition or species content of community.** The study of species content in a community is of paramount importance. The species content of a community can be studied by periodic collection and identification of plant species for the whole year. This will show the tolerance of each species for different environmental conditions (Hanson, 1950).

2. **Stratification and aspection.** The number of strata or layers in a community can be determined by general observation of the vegetation. If one periodically observes the flora for the whole year, changes in the appearance of vegetation may be apparent with the change in the season. This is known as ***aspection***. For this phenology of species in relation to different seasons of the year is recorded. On the basis of general observations of the vegetation a number of layers have been distinguished :

L_1—ground stratum like mosses, thallophytes, lichens, etc.,

L_2—herbaceous or ground flora,

L_3—middle layer or shrubby layer, and

L_4—top layer or canopy layer of trees.

In grasslands even two to three strata may be distinguished.

3. **Life-forms.** On the basis of general appearance and growth, the species of community are grouped into different life-form classes. The chief criteria for recognising life-form classes have already been given earlier in this chapter. On the basis of percentage values of different life-form classes, real nature of habitat and community can be understood.

4. **Sociability.** In a plant community, the individuals of species are not evenly distributed. Individuals of some species grow widely spaced while those of some other species are found in clumps or mats. The space relationship of plants is referred to as **sociability**. Individuals of some species when growing in clumps are either very weak or they tend to disappear due to hard competition and as such they cannot form big populations. Braun-Blanquet (1951) has recognised five sociability classes which accommodate different types of species.

Class 1. Shoots grow singly,

Class 2. Scattered groups or tufts of plants,

Class 3. Small scattered patches or cushions,

Class 4. Large patches or broken mats, and

Class 5. Very large mats of nearly pure population covering the entire area.

High degree of sociability is seen in those plants which produce large number of seeds with high germination percentage, show good survival of seedlings and mature plants and have many adaptive features. From gregariousness of species conclusions may often be drawn as to the nearness of approach to optimum conditions (Braun-Blanquet, 1932). This may explain the importance of the rough determinations of sociability values.

5. **Interspecific associations.** When the plants belonging to two or more different species grow near one another they form a community. This type of association is known as interspecific association. Interspecific association is possible if—

(*i*) the species can live in similar environment,

(*ii*) the species in question have similar geographical distribution,

(*iii*) the species belong to different life-forms (this reduces the competition), and

(*iv*) the plants of one species are related to the plants of other species. The relationship may be obligatory in one or both the directions.

Interspecific association can easily be observed in the field.

B. Quantitative analysis of Plant Community

The structure of sociological order in any plant community cannot be studied by observing each and every individual of plant species growing in a habitat. It is rather impossible. Therefore, rough estimate of species content of a habitat is made by observing the plant species at different places or sample areas, in the habitat. Several methods have been used by ecologists for this purpose which are as follows :

(1) Quadrat method,

(2) Transect method,

(3) Loop method, and

(4) Pointless or point method.

1. Quadrat Method of Sampling the Vegetation

The quadrat is a square sample plot or unit for a detailed analysis of vegetation. It is actually the sample-plot method of Clements (1898). It may be a single sample plot or may be divided into several subplots. In vegetational analysis, quadrats of any size, shape, number and arrangement may be used. In the study of a forest community quadrats of one-fifth acre are established to include maximum number of trees, while for studying shrubs and grass covers usually the quadrats of smaller sizes are used (Fig. 6.3). For grassland and low herbaceous community, the quadrats of one square metre size or 50 cm × 50 cm size or even 20 cm × 20 cm size may serve the purpose. The shape of quadrat is usually a square (Fig. 6.4 A and B) but rectangular, or even circular ones are also used. In some cases rectangular sample plots often give the best results. The ratio of breadth and length in rectangular plots is generally 1 : 2 or 1 : 4 or 1 : 8.

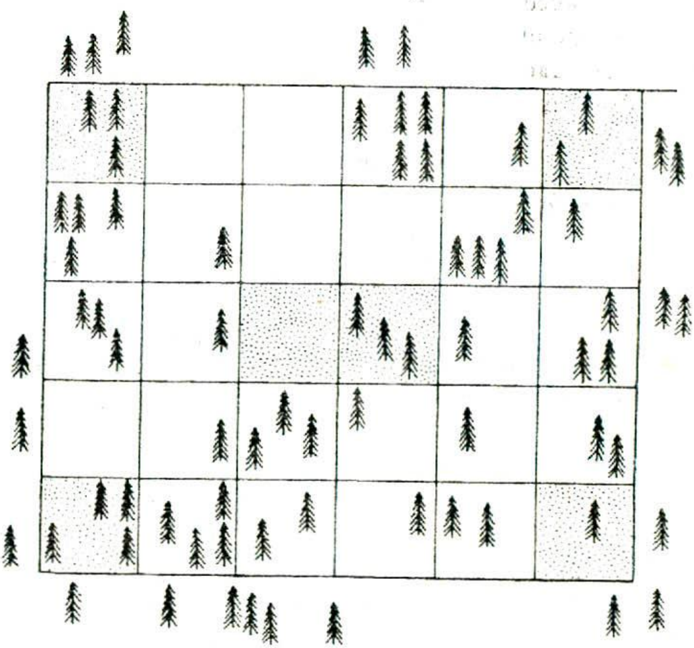

Fig. 6.3. Quadrat sampling method for population estimation.

Kinds of Quadrats. Quadrats are named according to the use. These are of the following types :

(*i*) **List quadrats.** When the organisms encountered in the sample plot are listed by their names, the quadrat is called *list quadrat.* It includes all the species botanically identified or otherwise. A series of list quadrats gives floristic analysis of the community. This is used for studying the frequency of different species.

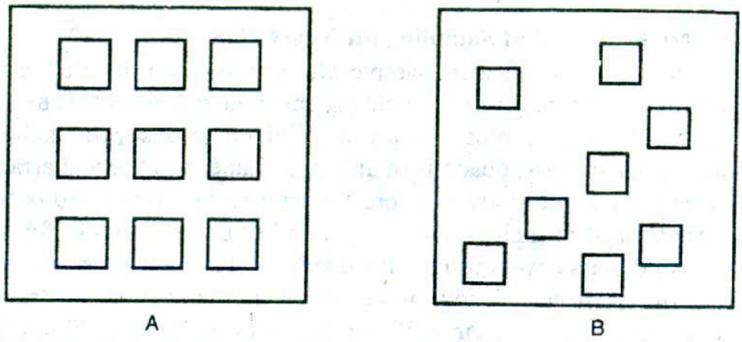

Fig. 6.4. A and B—Arrangement of quadrats in the study area A—Systematically distributed quadrats. B—Randomized quadrats.

(*ii*) **Count quadrat or list-count quadrat.** When the species name and the number of individuals of each species found in the sample area are recorded, the sample plot is called *count* or *list-count* quadrat. This type of plot is usually used in forest survey work.

(*iii*) **Cover quadrat.** When the actual or relative coverage is recorded usually as percentage of ground area covered or shaded by vegetation, the sample area is known as *cover quadrat.*

(*iv*) **Chart quadrat.** Quadrats that are mapped to scales to show the location of individuals of species are called chart quadrats. Individuals plants are recorded on miniature quadrat on a graph paper often with the help of an instrument called plantograph. This is very tedious work but where long range studies of vegetational changes are being made, this method provides a big picture.

So far as the distribution of quadrats in the study area is concerned, statistically reliable estimates are obtained by randomized plots. This is done in the following way :

On the map of the area under study a series of horizontal and vertical grid lines are laid and then these lines are numbered. The numbers of horizontal and vertical lines are written separately on small square pieces of paper. The paper pieces bearing the numbers of grid lines are placed in two separate beakers (one for horizontal grid numbers and the other for vertical grid numbers) and paper-pieces in each beaker mixed. Then the pairs of numbers are drawn out from the beakers and the position of each plot is located by putting the point given by the paired numbers.

As regards the selection of appropriate size of quadrat for sampling the vegetation, the quadrat selected should be of such small size as may cover the maximum number of species. There is a method for determining the minimal area of the sample plot. In this, sampling is done by using a geometric system of nested plots (Fig. 6.5). In plots of different sizes, number of species found in them are counted and recorded separately.

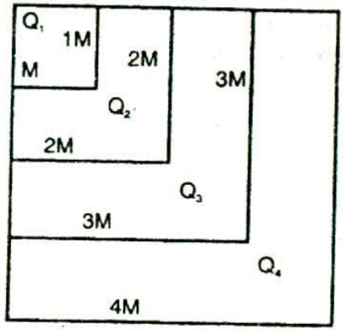

Fig. 6.5. Nested quadrats.

Then the numbers of species found in the plots of different sizes are plotted on vertical axis (O-Y axis) against sample plot sizes plotted on the horizontal axis (O—X axis). The resulting sigmoid curve will be obtained. This is called *species-area curve* (Fig. 6.6). Braun-Blanquet (1932), Oosting (1958), Misra and Puri (1954) and many other prominent ecologists of the world have used species-area curve for determining suitable area of the quadrat. Such a curve is obtained because as the size of sample plot is increased the number of species increases in the initial stage but only up to certain plot size, and later the number of new species added declines and finally the curve tends to become horizontal. Thus there is little to be gained by increasing the plot size. The desirable minimal quadrat size is determined by locating the point on curve where line takes horizontal course and joining it to the horizontal axis will indicate the minimal size of small plot.

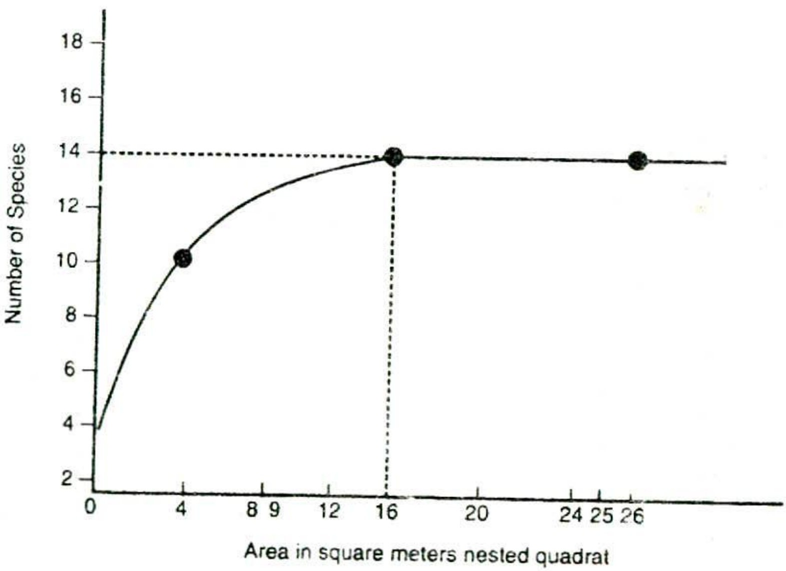

Fig. 6.6. Species-area curve.

In a well stratified community, the study of different strata is done with the help of different sized quadrats. For the tree and shrub strata large sized quadrats are taken but for ground vegetation small sized quadrats are used. The minimal sizes of quadrat are determined by "species-area curve" method.

In the same way, the minimum number of quadrats to be taken is also determined.

2. Transect Method

A cross-section of an area used as a sample for recording, mapping or studying vegetation is called ***transect***. It may be a strip, belt or a line across the area of study. The species occurring along these strips or lines are recorded. Because transect is continuous through the study area, it can be applied in studying the gradual and continuous changes in the vegetation along the line or strip with the change in environment. On the slopy area, the transect is laid between two points at different altitudes.

The transects are of two types :

(*i*) Belt transect, (*ii*) Line transect.

(*i*) **Belt transect.** It may be established as follows :

(*a*) The total area of the site to be studied is divided by 5 or 10 to obtain the total number of sample areas.

(*b*) A series of belt transects of predetermined width and length are laid and the belts are divided into equal sized segments (Fig. 6.7). These segments are sometimes called quadrats, but they differ from true quadrats in that each of them represents one observation point. Each segment within a belt is a part and the belt as a whole is one sampling unit.

(*c*) Names of species and number of individuals of each species in each unit are recorded.

The belt transect method is used to estimate abundance, frequency, and distribution of species in the community.

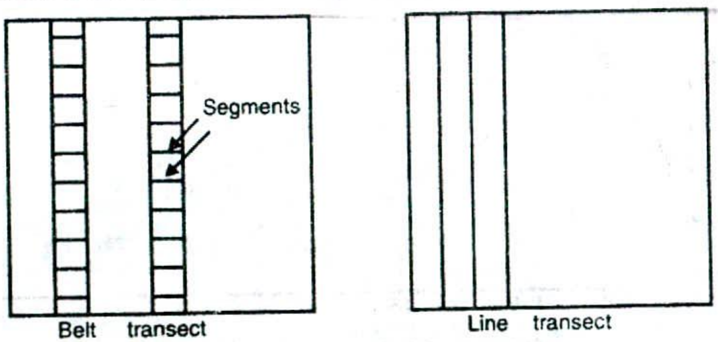

Fig. 6.7. Transects

(*ii*) **Line transect.** It is one dimensional transect. In this method, observation is taken on lines that are laid randomly or systematically over the study area (Fig. 6.7). The procedure is as follows :

(*a*) A metric steel tape or steel chain is stretched between two stalks 33.5 metres or one chain apart.

(*b*) The line is considered to be a one centimetre wide belt extending along one side of the tape or chain.

(*c*) The observer moves along the lines and records plant species and the distance they cover along the line transect. For grasses, rosettes and dicot herbs, the distance covered is measured along the line at ground level. For shrubs and tall herbs, the shadow or foliage cover is measured.

(*d*) Twenty or thirty randomly placed lines under most conditions adequately sample the community.

The following information can be obtained by this method :

(*i*) The number of times each individual species appears along the transect.

(*ii*) The occurrence percentage for each species in relation to the total species.

(*iii*) The total linear distance in cm of each species along the line.

(*iv*) The total distance of intercept by all species per 30 m line.

3. The Loop Method

This is a simple, accurate and quick method for sampling of only grassland and low herbaceous communities. It is used for determining community composition, species frequency and range condition. In this method equally spaced 100 small circles or loops located along a stretched line are used as observation points. The procedure of loop method of sampling is as follows :

(*a*) A small wire loop of 2 cm diameter is made.

(*b*) A point is located at random in the community and from the point 33.5 m long steel tape is stretched out. The observation points are marked in each metre at 33 cm, 66 cm, and 100 cm mark. In this way 99 observation points are marked in 33 metre distance. Near the end of the tape at 33.33 metre mark an additional point is marked. This brings the total number of observation points to 100.

(*c*) At each observation point wire loop is dropped to the right side of the tape and species encountered in the circle is recorded.

In this method 20 to 30 transects under most conditions adequately sample the community. Since 100 observation points are used in each line, the sum-totals are read as percentage. By this method species contents and cover are easily computed.

4. Pointless or Point Method

In this method of sampling observations are taken on the point in the study area where a nail or set of nails touch the ground on grid lines or at random places. There are several point methods of sampling but here only the following two methods will be discussed :

(*i*) Point frame method. (*ii*) Point centre method.

(*i*) **Point frame method.** This method was introduced by Levy and Maiden (1933). It is done with the help of point frame. This consists of a scale like frame, supported by a pair of legs. The frame bears 10 equidistant holes having 60 cm long pointers or pins (Fig 6.8). It is placed one after another at several observation points in the study area and the plant species that are hit by the pointed end of the pointers or nails are recorded. Besides this, the number of times the species are hit, and the total number of points taken are noted. From these values the quantitative structure of community is explained. This method is employed in the study of grassland and low herbaceous communities even on uneven ground.

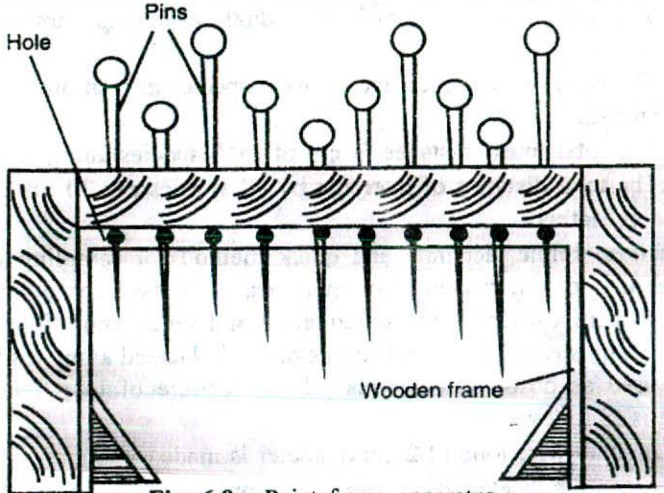

Fig. 6.8. Point frame apparatus.

(*ii*) **Point Centre or Quarter method.** In this method of sampling four measurements are taken at each observation point. The observation points can be mechanically placed along a straight line or they can be located at random. Quarter method was first described by Cotton and Curtis (1956). In this method an easy instrument is used which consists of a brass needle or a nail fitted with rubber cork and compass on the top (Fig. 6.9). The procedure of sampling is as follows :

(*a*) At each observation point the needle is fixed in the ground. This is central point.

(*b*) The working area is divided into four quarters or quadrats by visualizing two grid lines predetermined by the compass at right angles. Both the lines should cross each other at the central point.

(*c*) Now in each of the four quarters plant nearest to the central point is spotted and species recorded. The distance of each plant from the central point and also the basal diameter of the plant are measured.

(*d*) Tally at least 50 such points.

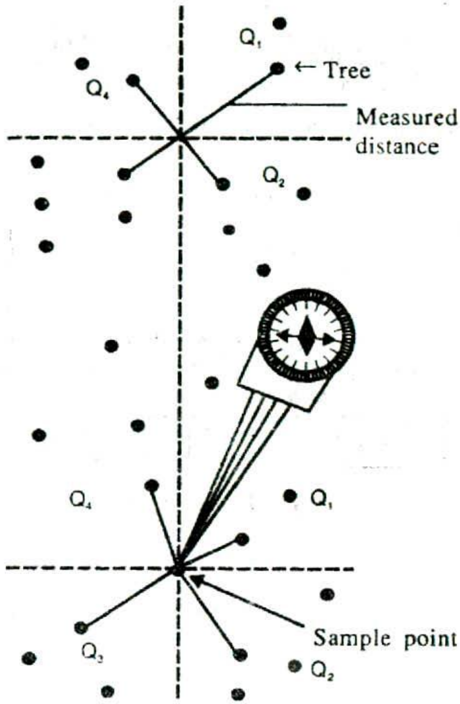

Fig. 6.9. Quarter or Point centre method of sampling.

Quantitative Structure of Plant Community

Coexistence and competition both are affected directly by the number of individuals in the community. Therefore, it is essential to know the quantitative structure of community. To characterise the community as a whole certain numerical constants called parameters are used. The total count of individuals of each species, mean value of individuals of a species per plot, for example, are parameters. Frequency, density, abundance, shadow and area coverage of species in the community, importance value index, total estimates, index of association, index of similarity, and fidelity of species give a clear picture of community structure in quantitative terms. The value of a parameter as estimated from the samples is the estimate which is hoped to be accurate or close to the real value.

1. **Density.** The numerical strength of a species in relation to a definite unit space is called its density. The *crude density* refers to the number of individuals of a particular species per unit area, *e.g.*, 2000 plants of *Peristrophe* species per acre will be the density of this species. Each organism occupies only the area that can adequately meet its requirements. Thus the density of an organism refers to the area available as living space. This would be **ecological density**.

Density of a species per unit area

$$= \frac{\text{Total number of individuals of a species in all the sample plots}}{\text{Total No. of sample plots studied}}$$

Density of species in a field is determined by the method given in the following table :

In some cases, *e.g.*, grasses and vegetatively propagated plants, the term individual creates difficulty. In such cases, each aerial tiller or shoot arising out from the soil is generally regarded as one individual.

Names of species	*Number of individuals in different quadrats each of 1 square metre size*										*Total No. of indivi-duals*	*Density*
	1	2	3	4	5	6	7	8	9	10		
1. *Evolvulus alsinoides*	5	4	7	×	1	3	9	2	8	5	44	$\frac{44}{10} = 4.4$ plants/m^2
2. *Indigofera sp.*	×	7	6	9	2	4	×	1	5	×	34	$\frac{34}{10} = 3.4$ plants/m^2
3. *Peristrophe sp.*	3	1	4	×	×	×	1	2	×	7	18	$\frac{18}{10} = 1.8$ plants/m^2
4.												
5.												
6.												

The proportion of density of a species to that of stand as a whole is referred to as relative density.

The following formula is used for calculating relative density of a species :

$$\text{Relative density of a species} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of individuals of all species}} \times 100$$

2. **Frequency.** In the community, the individuals of all the species are not evenly distributed. Individuals of some species are widely spaced while those of some other species are found in clumps or mats. The distribution patterns of individuals of different species indicate their reproductive capacity as well as their adaptability to the environment. Frequency refers to the degree of dispersion in terms of percentage occurrence. In order to study the frequency of species in an area, the study area is sampled by any sampling method at several places in desired pattern or at random and

only the names, not the numbers, of individual species encountered in each sample are listed. The frequency of a species is determined with the help of the following formula :

$$\text{Frequency} = \frac{\text{total no. of quadrats in which the species occur}}{\text{total no. of quadrats studied}} \times 100$$

Suppose, species 'A' occurred in 4 quadrats out of total ten quadrats studied, the frequency of species A will be

$$\frac{4}{10} \times 100 = 40\%$$

If the line or belt transect method is used for sampling then each line or belt is recognised as one quadrat for the purpose of frequency calculation.

If point frame method of sampling is used, the frequency is calculated by the following formula :

$$\text{Frequency of a species} = \frac{\text{Total no. of hits the species secured} \times 100}{\text{Total hits made}}$$

For calculating the frequency, the following pattern is adopted :

Species	*Number of sample plots*										*Frequency percentage*
	1	2	3	4	5	6	7	8	9	10	
1. *Evovulus sp.*	×	×	–	–	×	×	–	–	×	×	$\frac{6}{10} \times 100 = 60\%$
2. *Peristsophe bicalyculata*	–	–	×	×	×	×	–	×	–	–	$\frac{5}{10} \times 100 = 50\%$
3. *Cynodon sp.*	×	×	×	×	×	×	×	×	×	–	$\frac{9}{10} \times 100 = 90\%$
4. *Euphorbia sp.*	×	–	–	–	–	×	×	×	–	×	$\frac{5}{10} \times 100 = 50\%$
5. *Boerhaavia sp.*	–	–	–	–	–	–	–	×	–	×	$\frac{2}{10} \times 100 = 20\%$
6.											

(In the above table, the occurrence of species is marked by ×)

If the individuals of a species are evenly distributed over the area they may occur in all the sample plots and thus the frequency of species will be 100%. Poorly dispersed species will occur only in a few quadrats and their frequency will be low. This indicates that higher the frequency value of a species in the area the greater will be the uniformity in the spread.

Raunkiaer recognized five frequency classes of plant species in the community on the basis of their frequency percentages. These are as follows :

Class A—1 to 20% frequency
Class B—21 to 40% frequency
Class C—41 to 60 % frequency
Class D—61 to 80% frequency
Class E—81 to 100% frequency

Raunkiaer (1934) suggested that the number of species in frequency class A is greater than that of class B; B is greater than in class C, class C is greater, or equal or lesser than class D; and D is lesser than class E.

$$A > B > C \overset{>}{\underset{<}{=}} D < E$$

. This is also read as Raunkiaer's '*frequency law*'.

From the above frequency law it is apparent that the species with low frequency value are higher in number than the species with higher frequency value in most natural communities.

The dispersion of species in relation to that of all the species is termed as relative frequency of a species. Relative frequency is determined by the following formula :

$$\text{Relative frequency of a species} = \frac{\text{Frequency of the species in stand } x}{\text{Sum of the frequencies for all species in stand } x} \times 100$$

3. **Abundance.** The estimated number of individuals of a species per unit area is referred to as abundance. To determine abundance, the sampling is done by quadrat or other methods at random at many places and the number of individuals of a species is added for all the quadrats studied. The abundance is determined by the following formula :

$$\text{Abundance of a species} = \frac{\text{Total number of individuals of the species in all quadrats}}{\text{Total number of qudrats in which the species occurred}}$$

The abundance is usually expressed by assigning the species to one of the following abundance classes :

Abundance Classes

Classes	*Stalks per square metre quadrat*
Rare	1 to 4
Occasional	5 to 14
Frequent	15 to 29
Abundant	30 to 90
Very abundant	100 +

Abundance refers actually to *density* of population in those quadrats in which a given species occurs. In low form of vegetation like grasslands abundance can be recorded by uprooting the plants.

4. Cover. The cover implies the area covered or occupied by the leaves, stems and flowers, as viewed from the top. The coverage is studied at the *canopy level* and the *basal region.* In forest, where several strata are well marked, each layer of vegetation is considered separately for measuring the coverage. Basal cover is best expressed as the **basal area**, the ground actually covered by the crowns or by stems penetrating the soil. In forest the basal area is the cross section area of a tree measured at 4.5 feet above the ground (cross section area of a tree at breast height). It is estimated by point method of sampling (quarter method). In grasslands, estimate of total spread of foliage has little meaning. Basal area in such cases refers to the coverage of ground one inch above the ground surface by stems and leaves. It is also called *herbage cover* (Fig. 6.10). The coverage can be measured by quadrat method, transect method and point method of sampling. Basal coverage of tree is measured at breast height. Basal area of tree is calculated by the following formula :

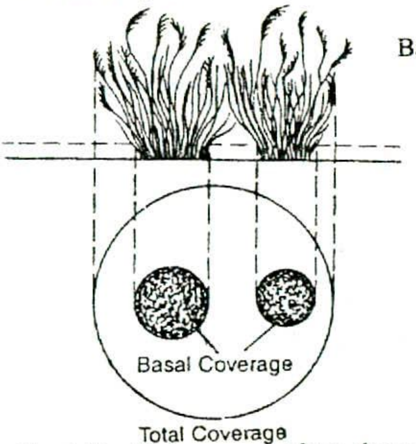

Fig. 6.10. Herbage cover of two clumps of grasses. Basal coverage of each clump one inch above the ground level is shown by shaded smaller circles and total coverage by large circle.

$$\text{Basal area per tree} = \frac{\text{Total basal area}}{\text{Number of trees}}$$

The area of coverage is used to express the dominance. The higher the coverage area the greater is the dominance. The average basal area is calculated out of average cross section areas of stems penetrating the soil. The average area of one stem multiplied by the density (no. of individuals per unit area) gives the basal cover per unit area.

Relative dominance (R.D.) is the proportion of the basal area of a species to the sum of the basal coverage of all the species in the area.

$$\text{Relative dominance of a species} = \frac{\text{Total basal area of the species in all the quadrats}}{\text{Total basal area of all the species in all the quadrats}} \times 100$$

5. Total estimate. Although abundance and coverage have their own importance in the community structure, yet they can be combined in a community description as total estimate. It is probably the best method for obtaining a complete general picture of a plant community. Total estimate (abundance plus coverage) scale as suggested by Braun-Blanquet is as follows :

+ Individuals of a species very few; coverage very poor.
1. Individuals of a species in plenty; but coverage small.
2. Individuals numerous if small and a few if large; coverage 5% of the total area.
3. Individuals few or many; coverage 25 to 50% of the total area.
4. Individuals few or many; coverage 50 to 75% of the total area.
5. Plant species over 75-100% of the total area.

6. **Association Index and Index of similarity.** The inter-specific association can be evaluated by association index and also by calculating the index of similarity. The index of similarity is utilized to compare two coexisting groups.

Suppose, out of 100 quadrats studies species A is encountered in 90 quadrats and species A in association with another species B is found only in 40 quadrats, the association index of species A is calculated by dividing the total number of quadrats in which A occurred in association with B by the total number of quadrats in which species A is found $\left(\frac{40}{90} = 0.44\right)$

Index of similarity is calculated as follows :

Suppose that in one group of coexisting species the number of plant species is 30 and in the other group the number of plant species is 20 and in first and second groups 15 species are common :

$$\text{Index of similarity} = \frac{2 \times \text{no. of common species}}{\text{Total number of species in both associations}} \times 100$$

$$= \frac{2 \times 15}{20 + 30} \times 100$$

$$= \frac{30 \times 100}{50} = 60$$

7. **Importance value.** In any highly heterogeneous plant community, data of frequency, density, abundance, and cover of species do not yield total picture of ecological importance independently. The overall picture of ecological importance of a species in relation to the community structure can be obtained by adding the values of relative density, relative dominance, and relative frequency. This total value out of 300 is called *Importance Value Index* (IVI) of the species. Once the importance values have been obtained for the species within the stands, the stands can then be grouped by their leading dominants according to the importance values and the groups are then placed in a logical order based on relationships of several predominant species. The dominants are arranged always in the order of decreasing importance values.

The importance of IVI was first pointed out by Curtis and McIntosh (1951). The IVI, as pointed out earlier, gives complete picture of sociological character of a species in the community but it does not give the dimension of relative density, relative dominance and relative frequency. The individuals as well as combined aspects of the position of a species in the community structure can be shown with the help of phytographs. In one type of phytograph a circle is made and then the circle is divided into four equal quarters by two diagonal lines lying at right angles to each other. Three radii from centre to circumference are divided into 100 segments and the fourth radius is divided into 300 parts (Fig. 6.11). On radius A is marked the value of relative frequency, on radius B is marked the value of relative density, on radius C is marked the value of relative dominance, and on D IVI on 0—300 scale. All these points on different radii are joined by lines. Thus, a phytograph illustrating the sociological characters and IVI of individual species is obtained.

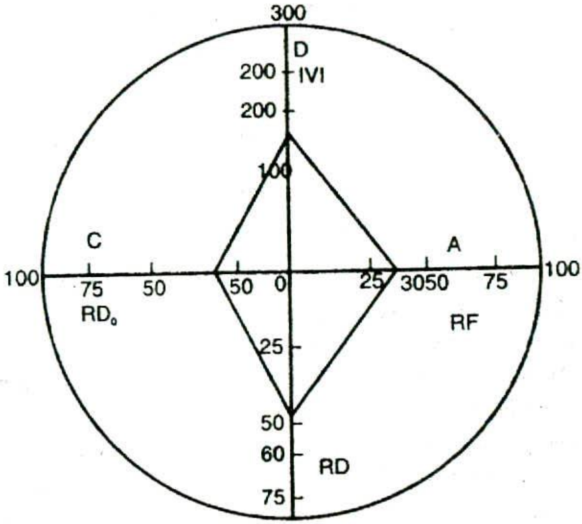

Fig. 6.11. Phytograph of species with Relative frequency (RF) 30%, Relative density (RD) value 60%, Relative dominance (RD) value 40% and Importance value index 130.

Synthetic Characters

Synthetic characters describe the make-up of a community. The chief synthetic characters used and advocated by Braun-Blanquet (1932), Cain (1932) and Nichols (1930) are presence, constance and fidelity.

Fidelity. The term fidelity refers to the faithfulness of a species to its community. In the community, there are different types of species. Some plant species are confined to one particular community and they are called indicator species. Some can flourish in several communities. According to Hanson (1950), it is a measure of ecological amplitude. Pandeya (1960) observes that characteristic species with high fidelity value has *low* *ecological* amplitude. **Ecological amplitude of a species** or its **tolerance** (Good, 1947) is the capacity of growing and reproducing within a certain range of environmental conditions. Fidelity of a species is expressed in relation to a particular community. A species may have high fidelity for one community and a low fidelity for another. Braun-Blanquet and Pavillard (1925), and Oosting (1956) recognised the following classes of species on the basis of their fidelity.

Fidelity Classes	*Characters*
Class—1	**Strange species** or **accidentals** which are either intruders from other community or relics from other successional stages.
Class—2	**Indifferent species** or companions which have no preference or affinities for any community.
Class—3	**Preferential species** which may be found in several communities but have affinity for only one community.
Class—4	**Selective species** which may occur rarely in other communities but have strong affinity to one particular community.
Class—5	**Exclusive species** which occur exclusively or almost exclusively in one community.

Species of 3rd, 4th and 5th fidelity classes are called **characteristic or key species of the community**.

Presence. It indicates the presence of a species in a stand. It is generally expressed in a scale of 1 to 5.

(*i*) *Rare,* which occur in 1% to 20% of stands examined

(*ii*) *Seldom present,* which occur in 21-40% of stands examined

(*iii*) *Often present,* which occur in 41-60% of the stands examined

(*iv*) *Mostly present,* which occur in 60 to 80% of stands examined

(*v*) *Constantly present,* which are present in 81 to 100% stands

Constance. It is the degree of "presence" in a unit area (sample area) instead of the whole stand. It actually improves the method of *presence* study, otherwise there is no fundamental difference between *presence* and *constance.* It is generally determined from frequency and the following 5 constance classes have been recognised.

Con. 1—1 to 20% frequency
Con. 2—21 to 40% frequency
Con. 3—41 to 60% frequency
Con. 4—61 to 80% frequency
Con. 5—81 to 100% frequency

QUESTIONS

1. What is plant community? Write an essay on the composition of plant community.
2. Discuss the structure of plant community.
3. Describe Raunkiaer's life-form classes of plant community.
4. Explain how a plant community has evolved.
5. Describe the various classificatory units of plant community.
6. Describe the various methods of studying plant community structure.
7. Write short notes on the following :
   Synecology, Ecotone, Biological spectrum, Ecesis, Consociation, Evolution of plant community, Density and frequency.

7

PLANT SUCCESSION

"Vegetation is dynamic, an ever-changing complex, now appearing quiescent and in complete equilibrium with the habitat, now displaying an obvious evidence of change" says E. Lucy Braun (1956). Observation of the natural changes in vegetation long ago resulted in the concept of succession. Under natural conditions the vegetation occupying a given habitat is called plant community. Since the community is not stable, it passes through many developmental stages in definite sequence and in definite direction generally from simple to complex and rarely from complex to simple. The gradual replacement of one type of plant community by the other is referred to as *plant succession.* According to E.P. Odum, "plant succession is an orderly process of community change in a unit area." Salisbury defines plant succession as follows :

"Plant succession is a competitive drift in which at each phase, until the climax, the constituent species render the habitat more favourable to their successors than to themselves."

Clements gave a very simple definition of plant succession. According to him, succession is a natural process by which the same locality becomes successively colonised by different groups or communities."

Succession is a complex universal process which begins, develops, and finally stabilizes at the climax stage. The climax is the final mature, stable, self-maintaining and self-reproducing stage of vegetational development in a climatic unit. Succession is generally progressive and thus it brings about—

(1) progressive changes in the soil conditions or habitats. These changes bring the habitat from extreme to optimum conditions of plant growth, and

(2) progressive changes in the life forms or phiads.

Causes of Succession

The main causes of succession are as follows :

(1) Climatic causes,

(2) Topographic causes, and

(3) Biotic causes.

1. **Climatic causes.** Plants cannot adjust with the long range variations in the climate. The fluctuating climate sometimes leads the vegetation towards

total or partial destruction and, as a result, the bare area develops which becomes occupied by such plants as are better adapted for changed climatic conditions. Drought, heavy snowfall, hails and lightnings are some of the important factors for the destruction of vegetation.

Sometimes new bare ground is formed by emersion of land from the bodies of water (ponds, rivers etc.).

2. **Topographic causes.** These are concerned with the changes in the soil. The following are two important soil factors which bring about changes in the habitat.

(*i*) **Erosion of the soil.** Sometimes surface soil is removed by a number of agents, such as wind, water currents, and rainfall. This process is known as soil erosion. In the process of erosion new and bare area is exposed in which new plant communities begin to appear one after another.

(*ii*) **Soil deposition.** It is one of the important causes that initiates succession. Soil deposition results owing to heavy storms, glaciers, snowfalls and landslides. If the deposition of soil takes place over an area already covered with vegetation, the plants occurring over there may be suppressed and destroyed. Deposition results in a new bare area on which succession of vegetation starts.

3. **Biotic causes.** Many biological or living agencies also affect the vegetation in many respects. Grazing, cutting, clearing, cultivation, harvesting, and deforestation, all caused by living agencies, are directly responsible for vegetational change. The parasitic plants and animals also affect the vegetation and destroy it.

Succession and Climax Concept

Plant succession is an orderly change of vegetation. It involves gradual and successive replacement of one plant population by the other. Any concrete example of plant succession taking place on a particular habitat is termed as *sere,* its various intermediate stages are called the *seral stages* and communities representing these stages are called the *seral communities.* Though the seral communities are not clearly distinct, yet they are recognised only because of some dominant plant species growing in them. The first plants which appear on the bare habitat are called pioneer plants. Actually speaking, plant succession is not a series of steps or stages but is continuous, and very slowly changing complex. It is dynamic process. The replacement of vegetation takes place individual by individual. There is no jump from one dominant community to an other. Dominant species of one community may persist along with some new migrants for several generations in a given area and bring about several changes in the habitat by their dense shades and leaf litter. When the habitat becomes extremely non-tolerable for the existing plants then the plants that are well suited to that habitat will come and become dominant. After several such changes, a stage may come when the habitat becomes occupied by most tolerant species that can reproduce and perpetuate well. Thus, the process leads to establishment of climax community; a mature, dominant, self-maintaining and slow changing plant community. Climax dominants are the species best adjusted to habitat and are able to take possession of the habitat and hold it against the new invading species. The treatments of climax and succession in Clementsian ecology imply the following assumptions about the orderliness of vegetation :

(1) The succession is an orderly growth process. Succession beginning in different environmental conditions finally reaches similar climaxes.

(2) The climax is determined only by climate, consequently climax and climatic region must correspond.

(3) The vegetations consist of climaxes and their successional conditions are clearly distinguishable.

Whittaker (1953) says that "successional processes give an impression of relative irregularities and disorderliness in detail together with a degree of orderliness in general pattern and trend."

Clements (1928) considered the climax formation as adult organisms, the fully developed community of a region, of which all other communities are the stages of development. Since the climate alone determines the climax formation, there is one true or climatic climax in a climatic region. The climatic climax is achieved where physical conditions of the substratum are not so extreme as to modify the effects of the prevailing regional climates. Sometime the climax is greatly modified by the physical conditions of soil, such as its topography and water content. Such a climax is known as *edaphic climax.* Relatively stabilized vegetation other than climatic or true climax may be produced in a given region because of distinctive soils or other habitat characteristics. These are referred to as developmental communities.

Sometimes the vegetation is prevented from reaching to the actual climax stage by the factors other than climate, as for example, fire, cutting, grazing, flooding, etc. Thus, the vegetation which is in the imperfect stage of development, is held indefinitely in stages preceding to real climax either by natural or by artificial factors. This type of imaginary climax is termed as *sub-climax.* Such plant communities would tend to reach real climax state if the causative factors are removed. Sometimes many disturbances cause modification or replacement of the true climax and consequently a modified sub-climax is formed which is termed as *disclimax.* If temporary change of the climate stops the development of vegetation before it has reached the expected climax, it forms *preclimax.* Sometimes the environment changes in such a way that the vegetation progresses beyond the expected climax stage. The new climax, thus formed, is termed *post-climax.*

Monoclimax and Polyclimax Theories

As regards the number of climaxes in a given habitat or climatic region, there are two different schools of thought. These are as follows :

(*i*) **Monoclimax theory.** According to Clementsian school, *there develops only one true climatic climax in a particular climatic region.* This concept is generalised as monoclimax theory.

(*ii*) **Polyclimax theory.** The second school of thought holds the view which is opposite to monoclimax concept. *It defines climaxes as the stabilized and self-maintaining plant communities and considers that a number of climaxes may exist in a given area.*

"The essential difference between monoclimax and polyclimax approaches seems to be the relative emphasis," says Whittaker (1963). According to him, those who support the monoclimax theory emphasize the essential unity of climax vegetations in a given area with allowance also for stabilized plant communities other than climax, but the exponents and supporters of polyclimax concept emphasize the inherent complexity of climatic climax with allowance also for prevailing climax community which characterizes the vegetation of given area and expresses its relations to climate."

Clements' monoclimax theory has been severely criticized in recent years on the ground that in the theory regionally prevailing undisturbed vegetation occupying the largest part of the land surface was regarded as real climax and other stabilized plant communities in the same area were recognised as subclimaxes which only theoretically could be replaced by the climax.

Braun, L.E. does not believe in monoclimax concept and comments "*to me, monoclimax seems impossible.*" He supports polyclimax idea but that too seems questionable to him. While working on the 'Deciduous forests of Eastern-north America' in 1950, Braun found many intergrading communities among which some were in the developing state and the others had reached the climax stage, some were very local in occurrence and extent (regional climaxes) and others recurred frequently over a big geographic extent (edaphic or topographic climaxes). Thus, his observations fully supported the polyclimax idea. Again in the year 1956, in the paper "Development of Association and Climax Concept", Braun supported the polyclimax idea and said, "the prevalence of any particular climax type may be due to control of climate; it may be related to the history of erosion cycles and past climate; it may be due to state of development of climax communities or more likely due to a combination of all.

The monoclimax theory, of course in modified form, has also been expressed by Dansereau (1954) and Walter (1954). Henry J. Oosting, of Duke University in his book, "Study of plant Communities", mentions that polyclimax theory is more practical. Nichols (1923) also expressed the same view. British ecologists under the leadership of Tansley maintained a general skepticism of monoclimax concept. Russian ecologists also have similar belief.

Smithusen (1950), Whittaker (1951, 53) and many other American ecologists support climax pattern or polyclimax concept and all believe in the fact that the climax state is determined by the environments of individual plant communities and not by regional climate, the latter identifies the climax as a community steady state and substitutes 'prevailing climax' for climatic climax.

KINDS OF SUCCESSION

Depending upon the nature of bare area on which it develops, the succession may be of two kinds : *primary* and *secondary*.

1. **Primary succession.** When the succession starts on the extreme bare area on which there was no previous existence of vegetation it is called *primary succession* or *presere*. This succession starts in the areas of extreme conditions and the process terminates after a long series of intermediate stages.

2. **Secondary succession.** This type of succession starts on the secondary bare area which was once occupied by original vegetation but later became completely cleared of vegetation by the process called denudation. This denudation process is brought about by the destructive agencies, such as fire, cultivation, strong winds, and rains. When the existing vegetation of an area becomes completely destroyed by destructive agents, it becomes naked or bare. Such a bare area is termed denuded area or secondary bare area. The succession progressing on such an area is also termed ***subsere***. Secondary succession has fewer stages than the primary succession and the climax is reached very quickly in the secondary succession. The primary and secondary successions may be of the following types :

(*a*) **Hydrosere.** The plant succession which starts in the aquatic environment is called "hydrarch." A series of changes taking place in the vegetation of hydrarch is called hydrosere.

(*b*) **Halosere.** It is special type of sere which begins on a salty soil or in saline water.

(*c*) **Xerosere.** When the vegetational succession develops in xeric or dry habitat, it is called xerarch or xerosere. Xerosere may be of two types :

(*i*) **Psammosere.** It refers to the vegetational succession that begins on the sandy habitat.

(*ii*) **Lithosere.** It refers to the succession that occurs on the rock surface.

(*d*) **Serule.** It refers to the miniature succession of micro-organisms, such as bacteria and different types of fungi on the fallen logs of decaying wood, tree bark, etc.

Irrespective of the types of succession, all the seres generally lead the plant communities towards the climax stage of mesic community (mesophytic or mixed mesophytic forests).

HYDROSERE

It is succession occurring in the aquatic environment. Such a type of succession does not necessarily lead the aquatic communities toward the development of land communities. If the body of water is large and very deep or very strong wave action and other powerful physical forces are at work, the succession results in a stable aquatic community in which any considerable further change is hardly recognisable. Succession is recognisable only if the colonisation of plant communities takes place in artificial small and shallow ponds, lakes, etc. where wave action speeds up the process by allowing the erosion of soil towards edge regions. In this way, the filling process also speeds up quickly and consequently the body of water disappears within few years time. Fig. 7.1 illustrates the different types of vegetation at different depths in a pond; floating plants in the central region; rooted hydrophytes in shallow region, amphibious plants in the marginal mud and trees developing in dry haibtat.

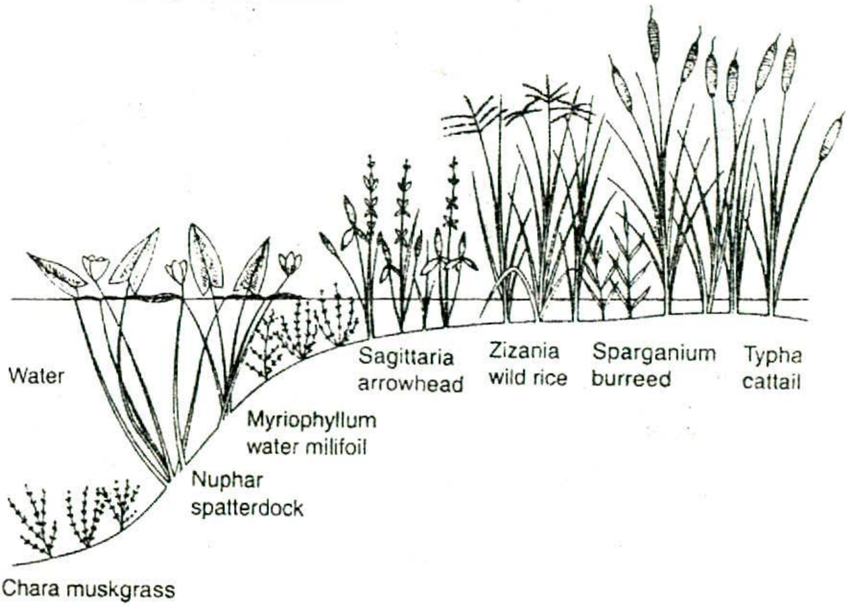

Fig. 7.1. Zonation of aquatic vegetation (hydrophytes) along a pond and along river banks. Note the changes in vegetation with water depth.

In a new and virgin pond hydrosere sta ts with the colonisation of phytoplankton and finally terminates into a forest (the climax community). The process of aquatic succession completes in the following stages (Fig. 7.2) :

1. **Phytoplankton stage.** In the initial stage of succession algal spores are brought in the body of water. The simple forms of life like bacteria algae and many other aquatic plants (phytoplankton) and animals

(zooplankton) floating in water are the pioneer colonizers. All these organisms add large amount of organic matter and nutrients due to their various life activities and after their death, they settle at the bottom of pond to form a layer of muck.

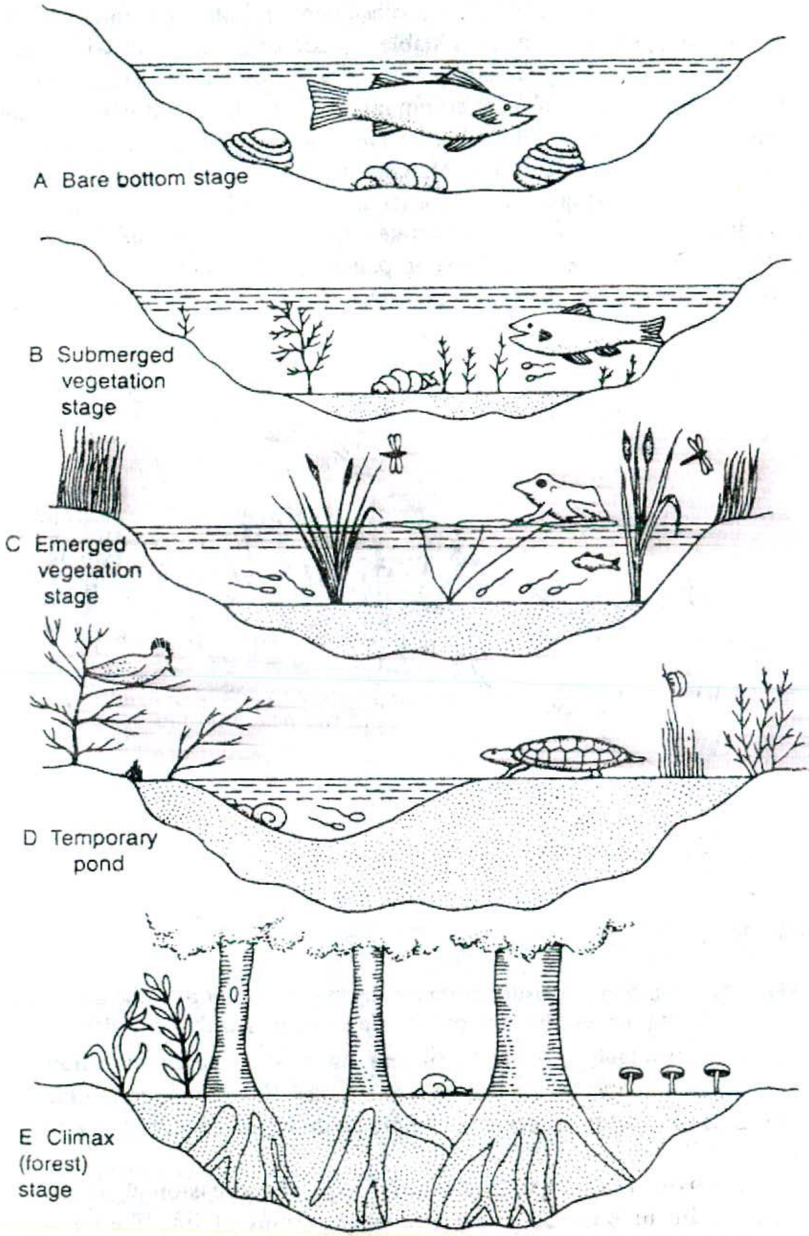

Fig. 7.2. Community succession in an open pond.

2. **Submerged stage.** The phytoplankton stage is followed by submerged plant stage. When a loose layer of mud is formed on the bottom of the pond, some rooted submerged hydrophytes begin to appear on the new substratum. The submerged aquatic vegetation develops in the regions of ponds or lakes where water depth is about 10 feet or more. The pioneers are *Elodia, Potamogeton, Myriophyllum, Ranunculus, Utricularia, Ceratophyllum, Vallisneria, Chara,* etc. These plants form tangled mass and have marked effects upon the habitat. When these plants die their remains are deposited at the bottom of the ponds or lakes. The eroded soil particles and other transported materials are also deposited at the bottom. This gradually raises the bottom of the ponds and lakes up. As this process of stratification progresses, the body of water becomes more and more shallow, consequently the habitat becomes less suited for the submerged vegetation but more favourable for other plants.

3. **Floating stage.** When the depth of water reaches about 4 to 8 feet, the submerged vegetation starts disappearing from its original place and then the floating plants make their appearance gradually in that area. In the beginning the submerged and floating plants grow intermingled but in the course of time the submerged plants are replaced completely. The most tolerant species in the area are able to reproduce and perpetuate. Their broad leaves floating on the water surface check the penetration of light to deeper layer of water. This may be one of the main causes responsible for the death of submerged plants. Due to continuous interaction between plant communities and aquatic environment, the habitat becomes changed chemically as well as physically. More water and air borne soil and dead remains of plants are diposited at the bottom. Thus, the substratum rises up in vertical direction. Important floating plants that replace the submerged vegetation are *Nelumbium, Trapa, Pistia, Nymphaea,* and *Limnanthemum* etc.

4. **Reed-swamp stage.** When the ponds and lakes become too shallow (water depth one to three feet) and the habitat is changed so much that it becomes less suited to the floating plants, some other plants which are well adapted to new environment will then come in. Under these conditions, the floating plants start disappearing gradually and their places are occupied by amphibious plants which can live successfully in aquatic as well as aerial environment. Important examples are *Bothrioclova, Typha, Phragmites* (Reed), etc. The foliage leaves of such plants are exposed much above the surface of water and roots are generally found either in mud or submerged in water. The foliage leaves form a cover over submerged and floating plants and thus they cut off light from the plants underneath them. Under such conditions neither submerged nor floating plants can survive. Further deposition of soil and plant debris at the bottom reduces the depth of water and makes the habitat less suitable for the pre-existing plants. When the bottom reaches very close to the water surface many secondary species,

such as those of *Polygonum, Sagittaria,* etc. make their appearance. Later, they also bring about such reactions by which the habitat becomes less suitable for most of the existing species, and consequently new successional step follows.

5. **Sedge Marsh or Meadow stage.** The filling process finally results in a marshy soil which may be too dry for the plants of pre-existing community. Now the plants well adapted to new habitat begin to appear in the pre-existing community in mixed state. Important plants that are well suited to marshy habitat are the members of cyperaceae and gramineae. The species of sedge (*Carex*) and rushes (*Juncus*), species of *Themeda, Iris, Dichanthium, Eriophorum, Cymbopogon, Campanula, Mentha, Caltha, Gallium, Teucrium, Cicuta,* etc. are the first invaders of marshy area. As these plants grow most luxuriantly in the marshes, they modify the habitats in several ways. They absorb and transpire a large quantity of water and also catch and accumulate plant debris and wind and water borne soil particles. Consequently a dry habitat results which may be totally unfit for the growth of normal hydrophytes. Gradually the mesophytes start appearing and after some time the sedge vegetation is totally replaced by them.

6. **Woodland stage.** In the beginning some shrubs and later medium sized trees form open vegetation or woodland. These plants produce more shade and absorb and transpire large quantity of water. Thus, they render the habitat more dry. Shade loving herbs may also grow under the trees and shrubs. The prominent plants of woodland community are species of *Buteazon, Acacia, Cassia, Terminalia, Salix, Cephalanthus,* etc.

7. **Climax forest.** After a very long time the hydrosere may lead to the development of climax vegetation. As the level of soil is raised much above the water level by progressive accumulation of humus and soil particles, the habitat become more dry and certainly well aerated. In such habitat, well adapted self-maintaining and self-reproducing, nearly stable and uniform plant community consisting mostly of woody trees develops in the form of mesophytic forest.

In the climax forest, all types of plants are met with. Herbs, shrubs, mosses and shade loving plants represent their own communities. Trees are dominant and they have control over the entire vegetation. Bacteria, fungi, and other micro-organisms are more frequently found in the climax vegetation. They react upon the habitat and make the soil rich in the organic materials. At the climax stage, a complete harmony develops between plant community and habitat. It is now clear that whole sere is a continuously but gradually changing complex in which the changes are forced by biotic, topographic or climatic factors. It is very slow process that cannot be observed in nature. It may require thousands of years to reach the climax stage. One can, however, observe the sequence of hydrosere as he moves in the lake or pond from the deepest region towards that shallower margin.

XEROSERE (A SUCCESSION ON BARE ROCK SURFACE)

Like hydrosere, a xerosere also completes in a series of several orderly steps; each seral stage being characterised by peculiar type of plant community and reaction.

Xeric succession commonly occurs on bare rock surfaces resulting from glaciation or from erosion by wind and water. The rocky habitat shows many extreme xeric conditions. As the rock is directly exposed to sun, the temperature of rock surface goes very high. There is no water and nutrient holding device on the exposed smooth surface of rock. In such a xeric habitat only those plants can survive which can resist the extreme drought. The pioneer colonisers on the bare area are crustose lichens which occur on the rock surface in the form of membranous crusts. Important crustose lichens are *Rhizocarpus, Lacidea,* etc. These plants grow only when water becomes available in the habitat. In dry periods, the pioneers, though they appear to be desiccated, remain alive. Their spongy nature enables them absorb excess amount of water and minerals. These lichens migrate through their spores and soridia and their migration is facilitated by wind and water.

The lichens secrete carbonic acid in excess. That acid is formed when excess CO_2 liberated in respiration combines with water. The reaction completes in the following way :

$$CO_2 + H_2O \rightarrow H_2CO_3 \text{ (carbonic acid)}$$

The carbonic acid reacts with the rocky materials and loosens the rock particles. The corroded rock particles together with decaying lichens make the first thin layer of soil on the rock surface. Nitrogenous compounds formed from the atmospheric gases during the lightning are brought to the soil by rains. Now the habitat becomes less fit for the existing plants and consequently primary colonisers begin to disappear from there.

After accumulation of little soil and humus, the rock surface, previously occupied by crustose lichens, now becomes covered with xeric foliose and fructicose lichens, *e.g., Dermatocarpon, Parmelia, Umbilicaria,* etc. These lichens have delicate leaf like thalli which cover the rocks and overshadow the pre-existing crustose lichens. When the supply of light is cut off, the crustose lichens begin to die. Foliose lichens absorb and accumulate water and minerals and check evaporation of surface water. They also secrete carbonic acid which further pulverizes or loosens the rocks into small particles. The water retaining capacity of the habitat increases with the further accumulation of soil particles and humus. Gradually the conditions become less favourable for the existing foliose and fructicose lichens.

When the habitat is changed, the existing foliose lichens start disappearing and in that area xerophytic mosses grow and become dominant. These plants usually grow in the crevices and depressions of the rocks where enough rock particles, humus and moisture are accumulated. Like lichens, mosses are also adapted to survive in extreme drought. These xerophytic mosses develop rhizoids which penetrate deep into the rocky soil. They cover the previous lichens and successfully compete with them for water and mineral nutrients. The decaying older parts of mosses form a thick mat over the rock surface. As this mat becomes more thick, it increases the water holding capacity of soil. Thus the habitat becomes relatively more wet. Now the next seral community may replace the moss community.

When the soil increases in thickness, the herbaceous vegetation, which consists mainly of annual and perennial herbs, develops very quickly. Increased m isture content of the soil favours the growth of herbs. The roots of these plants penetrate down almost to the level of unpulverized rock where they secrete acids and accelerate the process of rock disintegration. In this way, the thickness of soil on the rock surface increases to a considerable extent. Decaying leaves, stems, roots and other parts of the plants become deposited on the soil surface in the form of humus. This further increases the water holding capacity of the soil. These reactions make the habitat more suited for woody plants than to the existing herbs.

With the change of habitat, herbaceous vegetation also shows the sign of degeneration and xerophytic shrubs gradually occupy the area. Roots of shrubs also reach the surface of unpulverized rocks and corrode sufficient quantity of rock particles which make the soil more massive. Decaying leaves, twigs and roots of these shrubs also enrich the soil with humus. These important reactions bring about such conditions in the habitat as are most suited to the trees rather than to shrubs and herbs. Now the xerophytic trees invade the area which has been occupied previously by shrubs. The first trees growing in such areas are dwarf and widely spaced. With the increase in the water holding capacity of the soil these trees gradually disappear and subsequently the mesophytic types will develop. The trees are deeply rooted and their roots are profusely branched, hence they can absorb sufficient quantity of water and nutrients. These mesophytic trees grow densely and become dominant because their seedlings are shade tolerants. In the shade of mesophytic trees, some shade loving herbs and shrubs which are well adapted to humid atmosphere and moist soil also appear and they form their own communities. After very long interval when complete harmony develops between the plant communities and their environments the climax stage is established which remains unchanged unless some major environmental changes disturb it.

Successions on the bare areas do not always advance exactly in the sequences described above. Suppose, on a bare rock sand and gravels are deposited and succession starts on it, then the possibilities are there that some beginning stages may not develop at all and herbs, shrubs or even trees may appear as initial colonizers on such a habitat.

Succession on the sand-dunes starts with drought resistant grasses. The grass vegetation is followed by shrubs and trees. Primary succession on open land may lead to a grassland vegetation rather than a forest climax.

SOME EXAMPLES OF SECONDARY SUCCESSION OR SUBSERES

Subsere develops usually in settled areas which are geatly modified by the activities of man. It has fewer stages and it reaches the climax stage more quickly than the primary ones.

This type of succession may develop on secondary bare habitat, such as burnt lands, lumbered lands, disturbed agricultural lands, etc. The secondary bare area develops after the complete destruction of previous vegetation growing over it.

Secondary succession on burnt or lumbered bare areas may start with annual grasses and other herbs. This pioneer stage in due course of time will be replaced by perennial shrubs and trees. If such an area remains undisturbed by biotic agencies, climax woodland will be established.

From the study of succession, it becomes clear that the vegetation is not merely a haphazard covering of land by plants but it represents an orderly process of colonisation governed by interaction of plants and environments. It is mainly due to succession that the landscapes are changing continuously, some very quickly while others very slowly.

The knowledge of principles of succession is helpful in the management of forests, agricultural lands, mountain ranges and wild life areas.

QUESTIONS

1. What is plant succession? Write an essay on plant succession.
2. What is sere? Describe the various successional stages of hydrosere.
3. Describe the various development stages of pond studied by you. Give four examples of each stage.
4. Write short notes on the following :
   sere, causes of succession, climax, xerosere, secondary succession.

8

PLANT ADAPTATIONS

The living organisms react with their environments and they bear full impression of the environments in which they grow. In order to withstand adverse conditions of the environment and utilize to their maximum benefit the nutrients and other conditions prevailing therein, the organisms develop certain morphological, anatomical, physiological and reproductive features. Any feature of an organism or its part which enables it to exist under conditions of its habitat is called *adaptation.* Every organism develops certain adaptations and so does the population or a community. The completion of life cycle of an organism or stabilization of a community results through a series of adaptations which have survival value. Adaptations of survival value comprise such features as prevent destruction of vital vegetative tissues and help in large production and efficient dissemination of reproductive bodies. Warming (1895) had realised for the first time the influence of controlling or limiting factors upon the vegetation in ecology. He classified plants into several ecological groups on the basis of their requirements of water and also on the basis of nature of substratum on which they grow.

Warming classified plants on the basis of nature of substratum (soil) into the following groups :

(1) Plants of acidic soil (**Oxylophytes**)

(2) Plants of saline soil (**Halophytes**)

(3) Plants growing on the sand (**Psammophytes**)

(4) Plants growing on the surface of rocks (**Lithophytes**)

(5) Plants growing in the crevices of rocks (**Chasmophytes**).

Epiphytes are not included in the above classification because of the fact that they do not have permanent connection with the soil.

Warming's second classification (1909) of the plants is based on their water relations. The supply of water to the plants and regulation of transpiration are the factors that evoke great differences in plant forms and plant life. On the basis of their water requirement and nature of soils, the plants have been classified as follows :

1. **Hydrophytes :** Plants growing in or near water.

2. **Xerophytes :** Plants adapted to survive under the condition of very

poor supply of available water in the habitats. Xerophilous plants are further classified on the basis of their habitats as follows :

(*i*) Oxylophytes (on acid soils)

(*ii*) Halophytes (on saline soils)

(*iii*) Lithophytes (on rocks)

(*iv*) Psammophytes (on sand and gravels)

(*v*) Chersophytes (on waste land)

(*vi*) Eremophytes (on deserts and steppes)

(*vii*) Psychrophytes (on cold soils)

(*viii*) Psilophytes (savannah)

(*ix*) Sclerophytes (Forest and bushland)

3. **Mesophytes :** Plants growing in an environment which is neither very dry nor very wet.

The detailed description of only some important ecological groups is given here.

HYDROPHYTES

(*Greek, Hudor* = water and *Phyton* = Plant; water plant)

Plants which grow in wet places or in water either partly or wholly submerged are called hydrophytes or aquatic plants. Examples are *Utricularia, Vallisneria, Hydrilla, Chara, Nitella,* Lotus, *Ceratophyllum, Trapa, Pistia, Eichhornia* (water hyacinth), *Wolffia, Lemna, etc.* Aquatic environment provides a matrix for plant growth in which temperature fluctuation is at minimum and the nutrients occur mostly in dissolved state but light and oxygen become deficient with the increase in depth of water bodies. Zonation of aquatic vegetation with increasing depth is a device for maximum utilization of light energy. The aquatic environment is subject to water movements ranging from small vertical circulation to strong currents. Streams have a unidirectional movement and in seas the movement is reversible. The currents of water often abrade the inhabiting flora and varied modifications are encountered to withstand this abrasive action. Since water makes up a large proportion of the bodies of plants and animals (70 to 90% water in protoplasm), it affects all life processes directly. In plants, the rate and magnitude of the photosynthesis, respiration, absorption of nutrients, growth and other metabolic processes are influenced by the amount of available water. Low relative humidity increases water loss through transpiration and affects plant growth. Conversely, plants in the regions with high moisture show reduced transpiration. Some aquatic groups of higher plants probably originated from mesophytes. In the course of evolution several changes in the physiology, morphology and behaviour, all related to the aquatic mode of life, took place and by these evolutionary changes the mesophytic plants have become adapted to aquatic mode of life.

Classification of Hydrophytes

According to their relation to water and air, the hydrophytes are grouped into the following categories :

(*a*) Submerged hydrophytes

(*b*) Floating hydrophytes

(*c*) Amphibious hydrophytes.

(*a*) **Submerged hydrophytes.** Plants which grow below the water surface and are not in contact with atmosphere are called submerged hydrophytes. Such plants may be free-floating (Fig. 8.1) or rooted (Fig. 8.2). Example *Vallisneria, Hydrilla, Potamogeton, Najas, Ceratophyllum, Myriophyllum, Utricularia, Chara, Nitella* and a number of aquatic microbes.

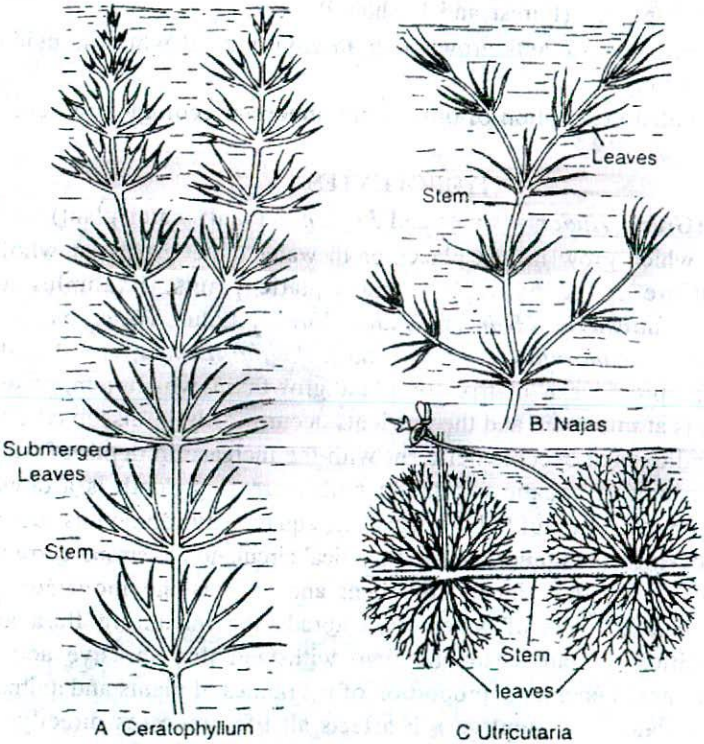

Fig. 8.1. Submerged floating hydrophytes.

(*b*) **Floating hydrophytes.** Plants that float on the surface or slightly below the surface of water are called floating hydrophytes. These plants are in contact with both water and air. They may or may not be rooted in the soil. On this ground, the floating plants have been divided into two groups.

(*i*) **Free floating hydrophytes.** These plants float freely on the surface of water but are not rooted in the mud. Examples—*Wolffia arhiza* and *Wolffia microscopica* (a rootless minutes duck weed). *Trapa bispinosa,*

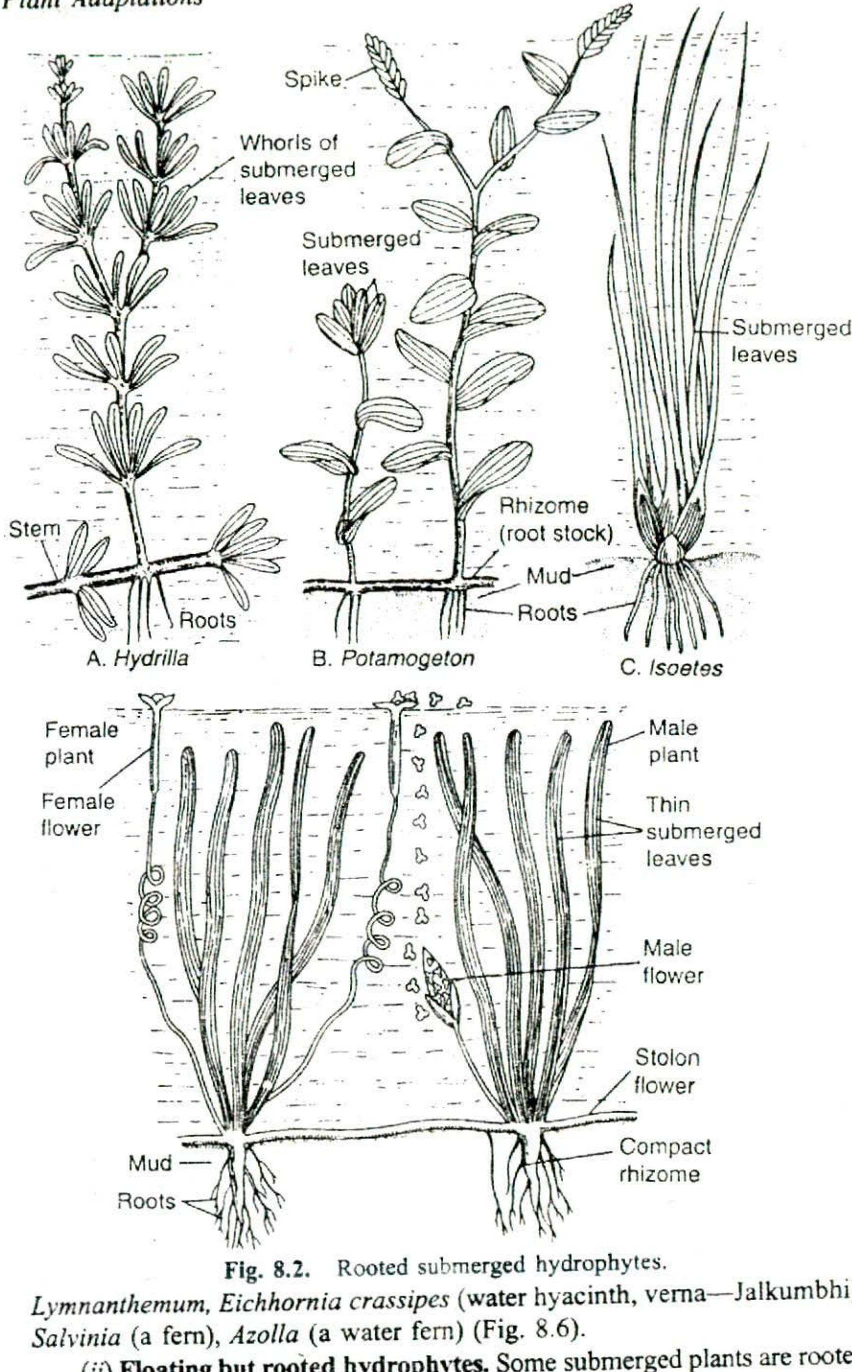

Fig. 8.2. Rooted submerged hydrophytes.

Lymnanthemum, Eichhornia crassipes (water hyacinth, verna—Jalkumbhi), *Salvinia* (a fern), *Azolla* (a water fern) (Fig. 8.6).

(*ii*) **Floating but rooted hydrophytes.** Some submerged plants are rooted in muddy substrata of ponds, rivers and lakes but their leaves and flowering shoots float on or above the surface of water. They are grouped as floating

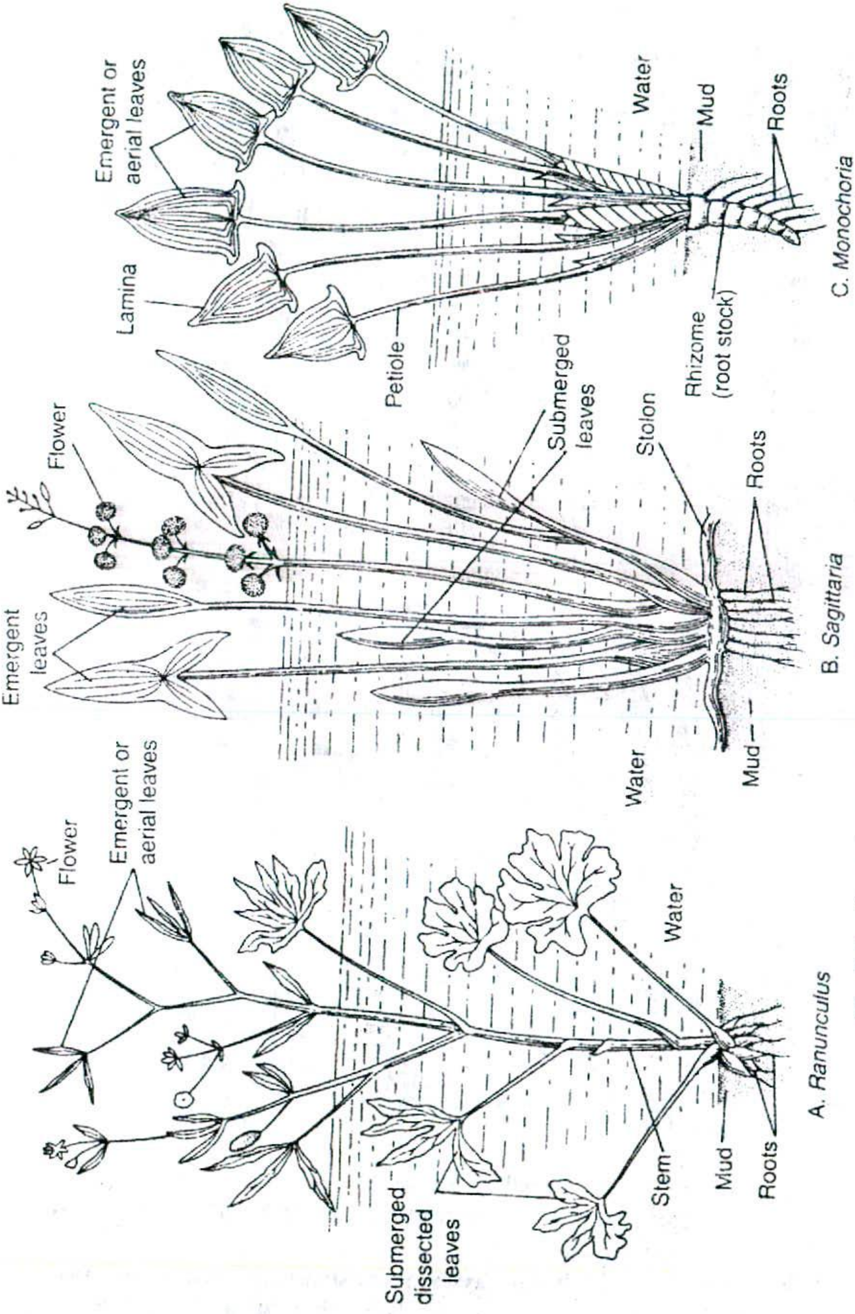

Fig. 8.3. Rooted emergent hydrophytes with heterophylly.

but rooted hydrophytes. Examples—*Nymphaea, Nelumbium speciosum* (Lotus), *Victoria regia* (water lily), *Ceratopteris thalictroides* (a hydrophytic fern of family Parkariaceae), etc. (Fig. 8.5).

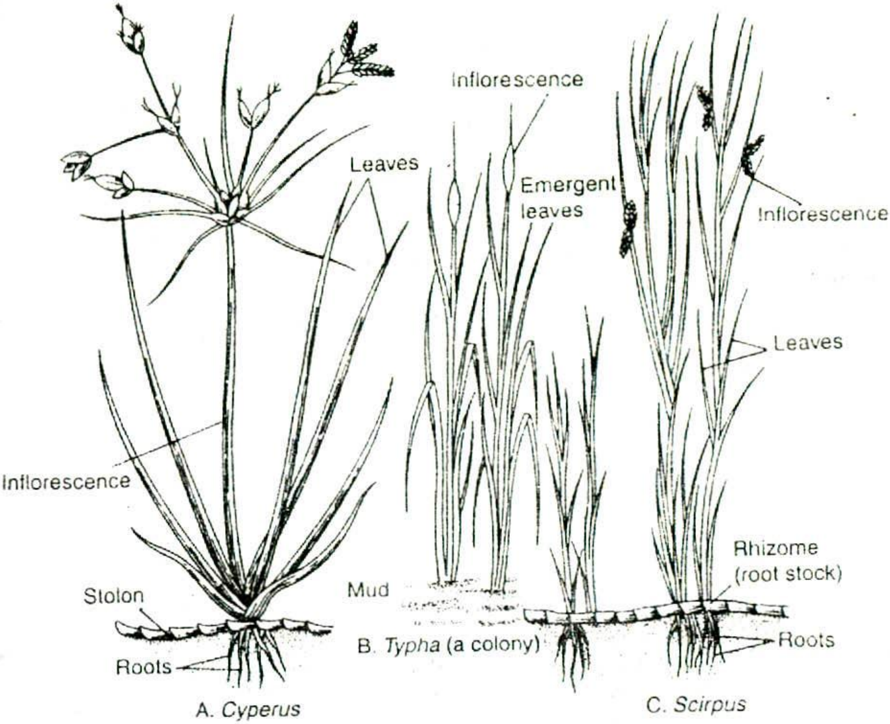

Fig. 8.4. Marsh plants.

(*c*) **Amphibious hydrophytes.** These plants are adapted to both aquatic and terrestrial modes of life. Amphibious plants grow either in shallow water or on the muddy substratum. Amphibious plants which grow in marshy places are termed as 'halophytes. Roots and some parts of stems and leaves in these plants may be submerged in water or buried in mud but some foliage, branches and flowering shoots spring well above the surface of water or they may spread over the land (Fig. 8.3). The aerial parts of these amphibious plants show mesophytic or sometimes xerophytic features, while the submerged parts develop true hydrophytic characters. Some varieties of rice plants, (*Oryza sativa*), *Marsilea. Sagittaria, Alisma, Jussiaea. Neptunia. Commelina. Polygonum, Ranunculus aquatilis, Phragmites, Enhydra fluctuans,* etc. are familiar examples o.' this group of hydrophytes.

In some amphibious plants the shoots are completely exposed to air as in land plants but the roots are buried in water lodged soil or mud. They are called *marsh plants.* The common examples of marsh plants are *Cyperus, Typha, Scirpus, Rumex,* etc. (Fig. 8.4).

Factors Affecting the Plants in the Aquatic Environment

These are listed below :

1. Temperature of water
2. Osmotic concentration of water
3. Toxicity of water

The osmotic concentration and toxicity are dependent upon the amount and nature of chemical substances dissolved in water. The physiology of aquatic plants is greatly affected by the change of osmotic concentration of water. The aquatic plants are subjected to less extremes of temperature because water is bad conductor of heat (*i.e.*, it takes long time in its heating and cooling). Hydrophytes are less affected as far as the transpiration from the plant tissue is completely out of question.

Hydrophytic Adaptations

As the aquatic environment is uniform throughout, the hydrophytes develop very few adaptive features. Important features of these plants are described in the following heads :

A. Morphological

(*i*) **Roots.** Root systems in hydrophytes are poorly developed which may or may not be branched in submerged hydrophytes. Roots are meaningless as the entire surface of the plant body which is in direct contact with water acts as absorptive surface and absorbs water and minerals. This may probably be the reason why roots in hydrophytes are reduced or absent. Roots of floating hydrophytes show very poor development of root hairs. Roots in floating plants do not possess true root caps but very often they develop root pockets or root sheaths which protect their tips from injuries (Fig. 8.5). Exact functions of these root pockets, however, are not fully understood. Some rooted hydrophytes like *Hydrilla* (Fig. 8.6), *Vallisneria spiralis, Elodia canadensis,* though they derive their nourishments from water by their body surfaces, are partly dependent on their roots for minerals from the soil. Roots are totally absent in some plants, *e.g., Ceratophyllum, Salvinia, Azolla, Utricularia,* etc. In *Jussiaea repens* two types of roots develop when the plants grow on the surface of water, some of them are normal while the others are floating roots which are negatively geotropic having spongy structures (Fig. 8.7). The floating roots keep the plants afloat.

(*ii*) **Stem.** In aquatic plants, it is very delicate and green or yellow in colour (Fig. 8.2 A, B). In some cases it may be modified into rhizome or runner, etc. (Fig. 8.2 D, 8.4).

(*iii*) **Leaves.** (*a*) In floating plants leaves are generally peltate, long, circular, light or dark green in colour, thin and very smooth. Their upper surfaces are exposed in the air but lower ones are generally in touch with water. In lotus plant petioles of leaves show indefinite power of growth and they keep the laminae of leaves always on the surface of water.

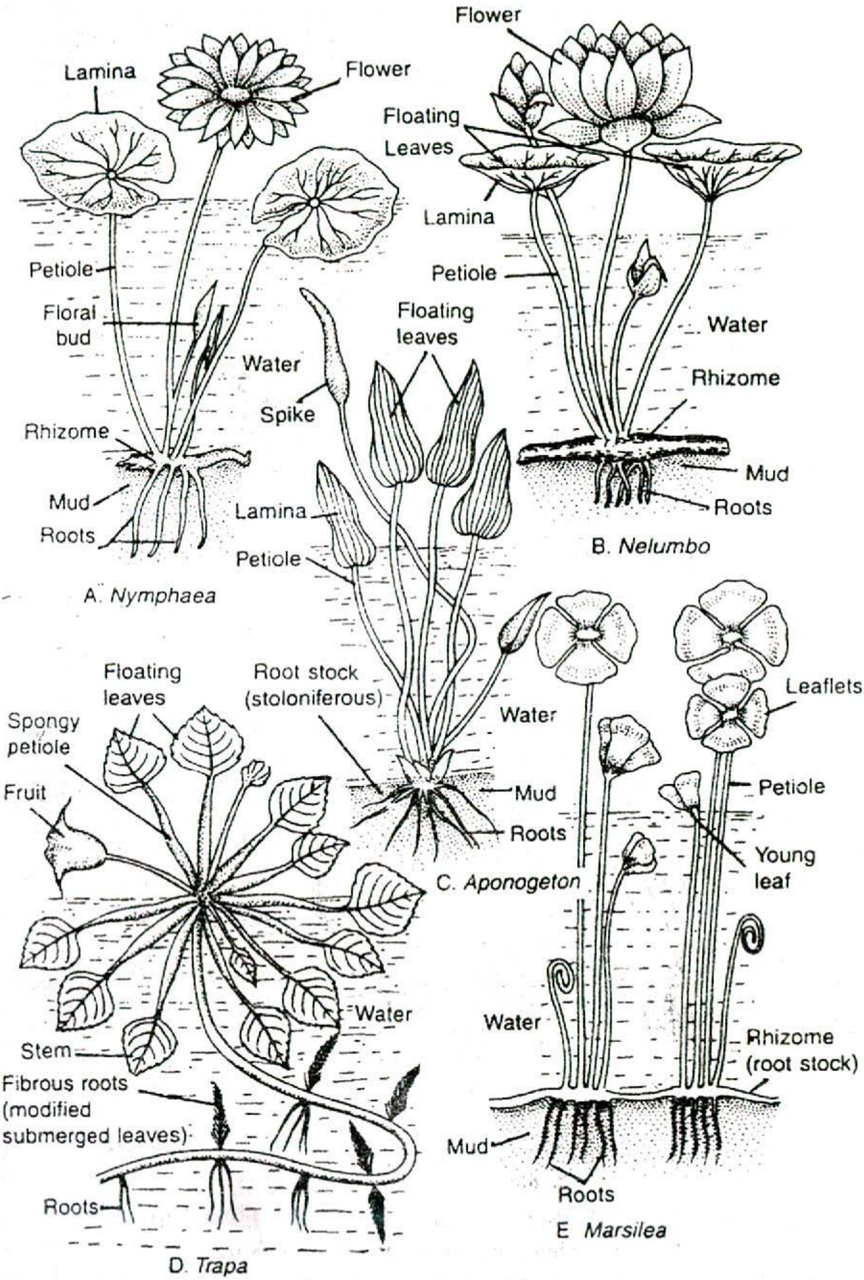

Fig. 8.5. Rooted hydrophytes with floating leaves.

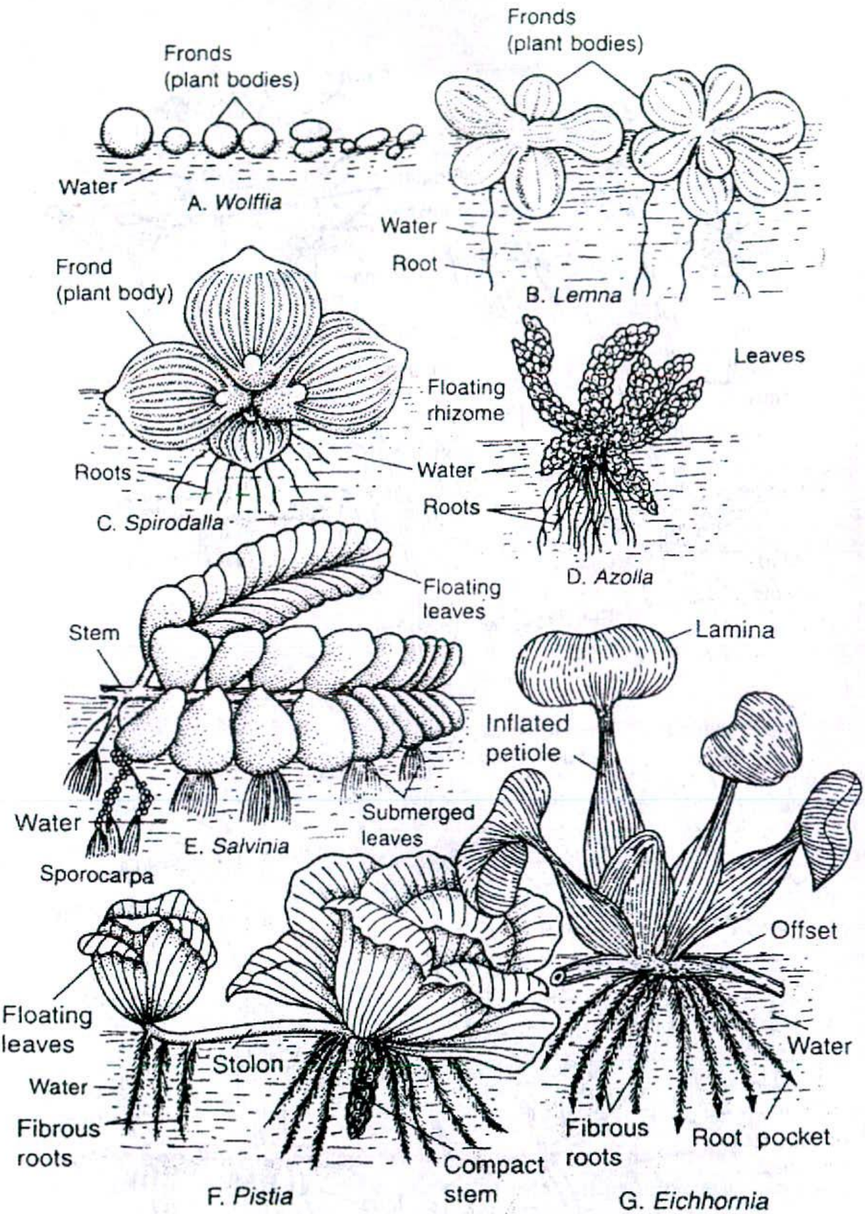

Fig. 8.6. Free floating hydrophytes.

(*b*) *Heterophylly.* Some aquatic plants develop two different types of leaves in them. This phenomenon is termed as heterophylly. Examples are *Sagittaria sagittaefolia, Ranunculus aquatilis, Limnophila heterophylla, Salvinia, Azolla* etc. In this phenomenon, generally the submerged leaves are linear ribbon shaped or highly dissected and the leaves that are found

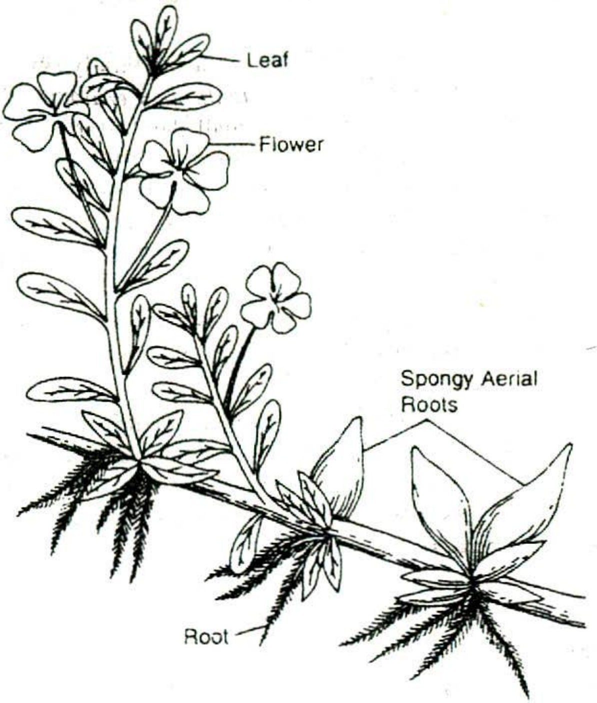

Fig. 8.7. *Jussiaea repens* showing spongy respiratory roots.

floating on or above the surface of water are broad circular or slightly lobed (Fig. 8.3 A, B, C). The occurrence of heterophylly is associated probably with the following characteristic physiological behaviours of these aquatic plants :

1. Quantitative reduction in transpiration.
2. The broad leaves on the surface overshadow the submerged dissected leaves of the same plant and thus they reduce the intensity of light falling on the submerged leaves. The submerged leaves require light of very low intensity.
3. Plants show very little response to drought because the necessity of excess water during drought period is compensated by submerged leaves which act as water absorbing organs.
4. Variation in the life-forms and habitats.
5. Broad leaves found on the surface of water transpire actively and regulate the hydrostatic pressure in the plant body.

(*c*) leaves of free floating hydrophytes are smooth, shining and frequently coated with wax. The wax coating protects the leaves from chemical and physical injuries and also prevents the water clogging of stomata.

(*d*) In floating plants of water hyacinth, *Trapa* etc., the petioles become characteristically swollen and develop spongyness which provides buoyancy to these plants (Fig. 8.6 F).

(*e*) Leaves in submerged hydrophytes are generally small and narrow. In some cases, *e.g., Myriophyllum, Utricularia, Ceratophyllum*, etc., they may be finely dissected (Fig. 8.2). The small slender terete segments of the dissected leaves offer little resistance against the water currents. In this way, plants are subjected to little mechanical stress and strain of water.

(*f*) In the Amphibious plants, the leaves that are exposed to air show typical mesophytic features. They are more tough than the leaves of other groups of hydrophytes.

(*iv*) Pollination and dispersal of fruits and seeds are accomplished by the agency of water. Seeds and fruits are light in weight and thus they can easily float on the surface of water.

(*v*) Vegetative reproduction is common method of propagation in hydrophytes. It is accomplished either through fragmentation of ordinary shoots or by winter buds. In algae, reproduction is accomplished by zoospores and other specialized motile or non-motile spores.

B. Anatomical Modifications

The anatomical modifications in hydrophytes aim mainly at :

1. Reduction in protecting structures;
2. Increase in the aeration;
3. Reduction of supporting or mechanical tissues;
4. Reduction of vascular tissues.

Various anatomical adaptations of hydrophytes are listed below.

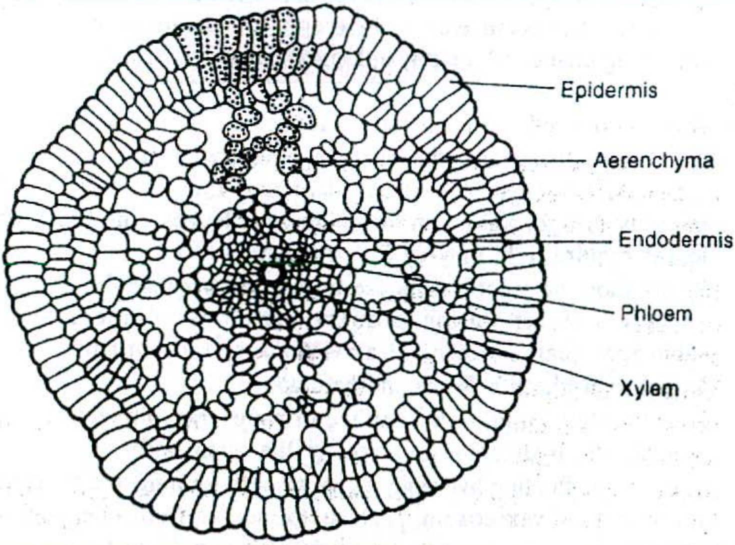

Fig. 8.8. T.S. of *Hydrilla* stem.

1. **Reduction in protecting structures.** (*a*) Cuticle is totally absent in the submerged parts of the plants. It may be present in the form of very fine film on the surfaces of parts which are exposed to atmosphere.

(*b*) Epidermis in hydrophytes is not a protecting layer but it absorbs water, minerals, and gases directly from the aquatic environment. Extremely thin cellulose walls of epidermal cells facilitate the absorption process.

(*c*) Epidermal cells contain chloroplasts, thus they can function as photosynthetic tissue, especially where the leaves and stems are very thin, *e.g. Hydrilla* (Fig. 8.8).

(*d*) Hypodermis in hydrophytes is poorly developed. Its cells are extremely thin walled.

2. **Increase in the aeration.** (*a*) Stomata are totally absent in submerged parts of the plants (Figs. 8.9, 8.10 C & D). In some exceptional cases,

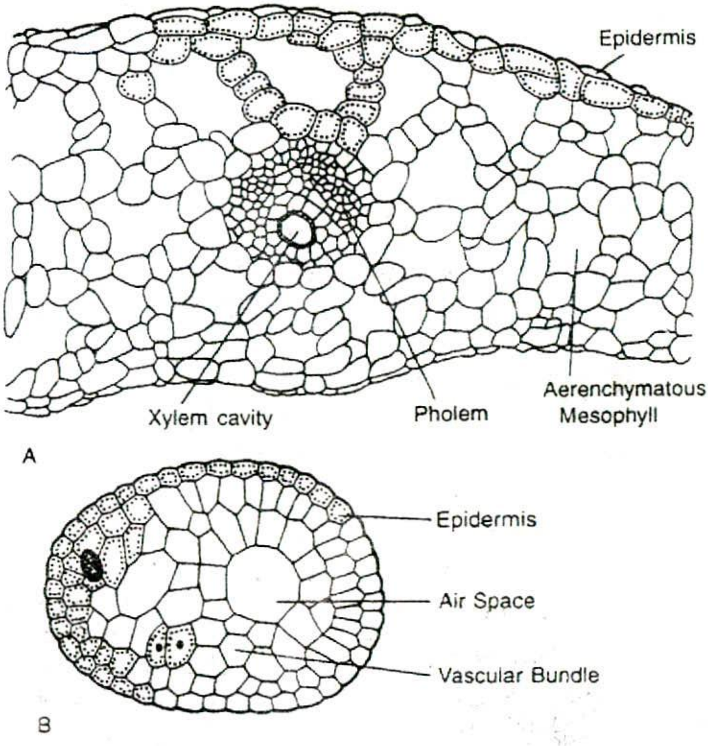

Fig. 8.9. A, B—T.S. of submerged leaves. *A. Vallisneria B. Ceratophyllum.*

vestigial and functionless stomata have been noticed. In these cases exchange of gases takes place directly through cell walls. In the floating leaves, stomata develop in very limited number and are confined only to

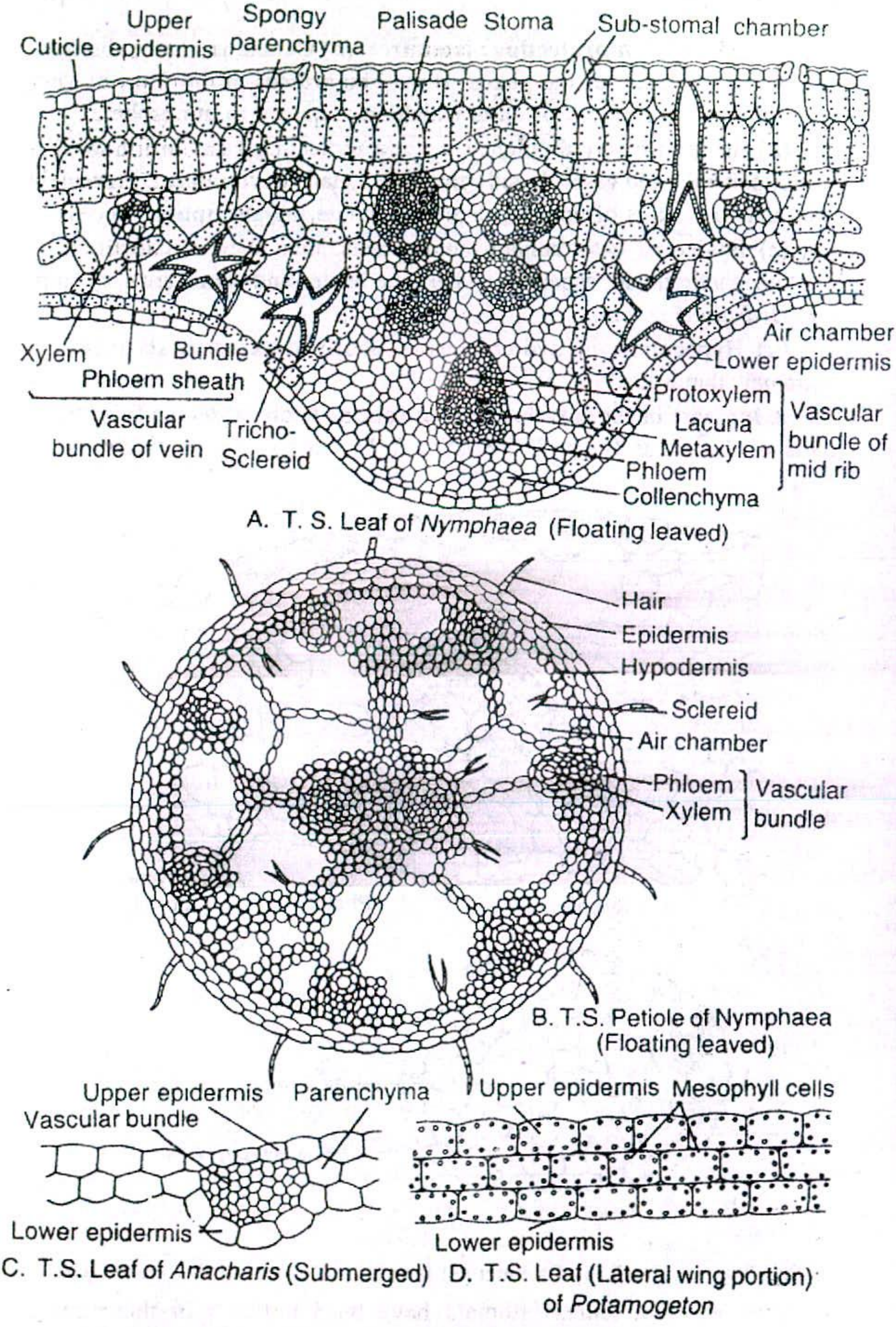

Fig. 8.10. Anatomical features of some hydrophytic leaves.

the upper surface (Fig. 8.10 A). In amphibious plants stomata may be scattered on all the aerial parts and they develop comparatively in larger number per unit area than those in the floating leaves (Fig. 8.11).

(*b*) *Air chambers.* Aerenchyma in submerged leaves and stem is very much developed. Air chambers are filled with respiratory gases and moisture. These cavities are separated from one another by one or two cells thick chlorenchymatous partitions. The different types of air chambers are shown in Figs. 8.8, 8.9 A, and 8.10. CO_2 present in the air chambers is used up in the photosynthesis and the O_2 produced in the process of photosynthesis and also that already present in the air chambers is used up in respiration. The air chambers also develop finely perforated cross septa which are called diaphragms (Fig. 8.12). The diaphragms afford better aeration and perhaps check floating. The aerenchyma provides buoyancy and mechanical support to aquatic plants. Air chambers are abundantly found in the fruits of hydrophytes rendering them buoyant and thus facilitating their dispersal by water.

Development of air chambers in the plants is governed by habitat. This point is clear from the anatomy of *Jussiaea suffructicosa.* In this case, air chambers develop normally if plants are growing in water but they seldom develop if the plants are growing on the land.

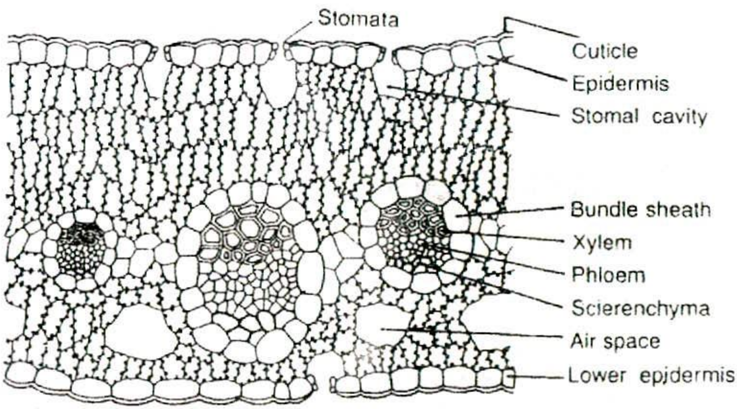

Fig. 8.11. V.S. of an amphibious leaf.

3. **Reduction of supporting or mechanical tissues.** (*a*) Mechanical tissues are absent or poorly developed in the floating and submerged parts of the plants because buoyant nature of water saves them from physical injuries. The thick walled sclerenchymatous tissue is totally absent in submerged and floating hydrophytes. They may, however, develop in the cortex of amphibious plants, particularly in the aerial or terrestrial parts (Figs. 8.13, 8.14 B, D). Generally elongated and loosely arranged spongy

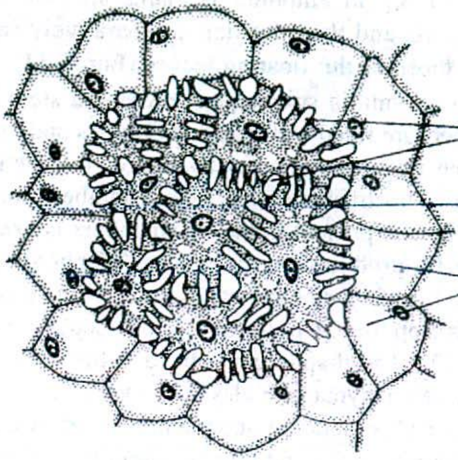

Fig. 8.12. Detailed structure of diaphragm of *Pontederia.*

cells are found in the plant body. These thin-walled cells, when turgid, provide mechanical support to the plants (8.15, 8.16 and 8.17).

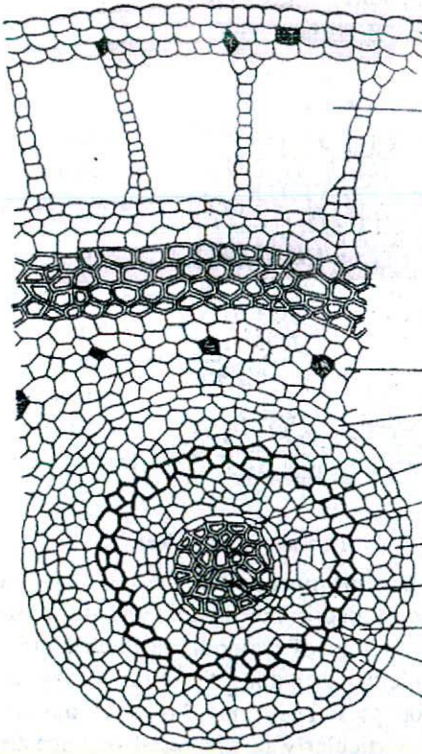

Fig. 8.13. T.S. of *Marsilea rhizome* (An amphibious hydrophyte).

(*a*) The reduction of absorbing tissue (roots act chiefly as anchors and root hairs are lacking).

(*b*) In water lily and some other plants, special type of star shaped lignified cells, called asterosclereids, develop which give mechanical support to the plants (Fig. 8.10 A,B).

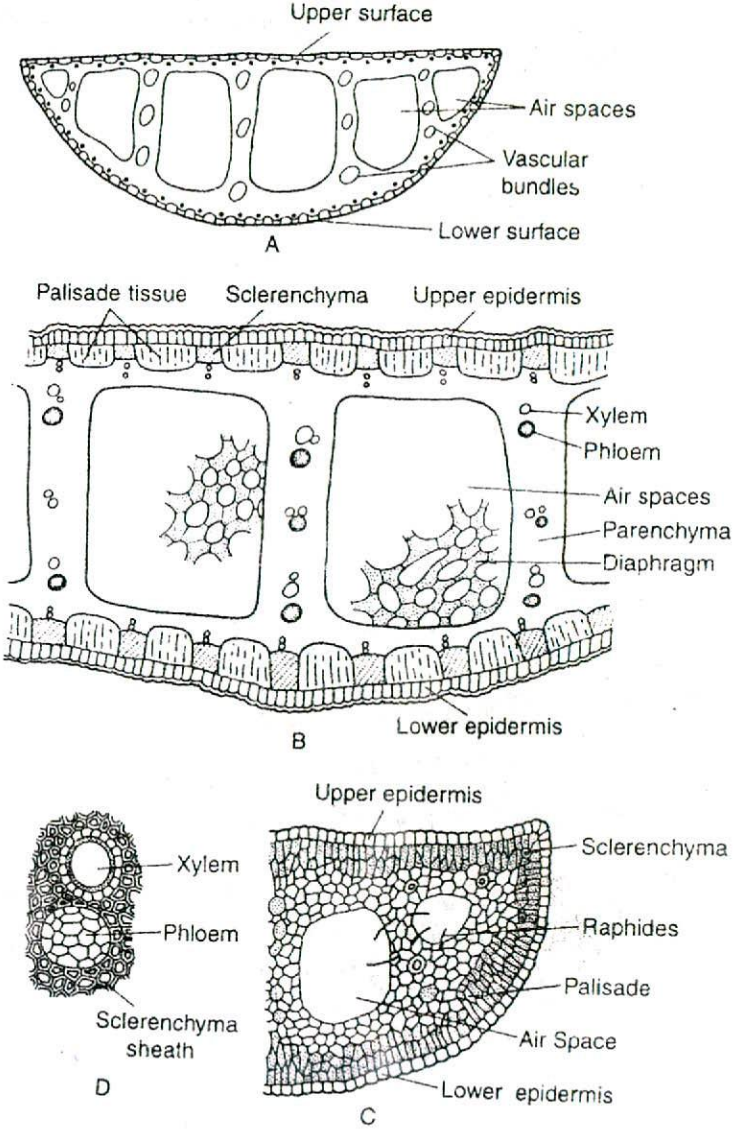

Fig. 8.14. Anatomy of leaf of *Typha,* a marshy hydrophyte. A : T.S. of leaf (diagrammatic), B : detail of a part of A; C, detail of corner of leaf, D : single vascular bundle.

4. Reduction of vascular tissues. Conducting tissue is very poorly developed. As the absorption of water and nutrients takes place through the entire surface of submerged parts, there is little need of vascular tissues in these plants. In the vascular tissues, xylem shows greatest reduction. In some cases, it consists of only a few tracheids while in some, xylem elements are not at all developed (Fig. 8.18). Some aquatic plants, however, show a lacuna in the centre at the place of xylem. Such spaces resemble typical air chambers (Fig. 8.8).

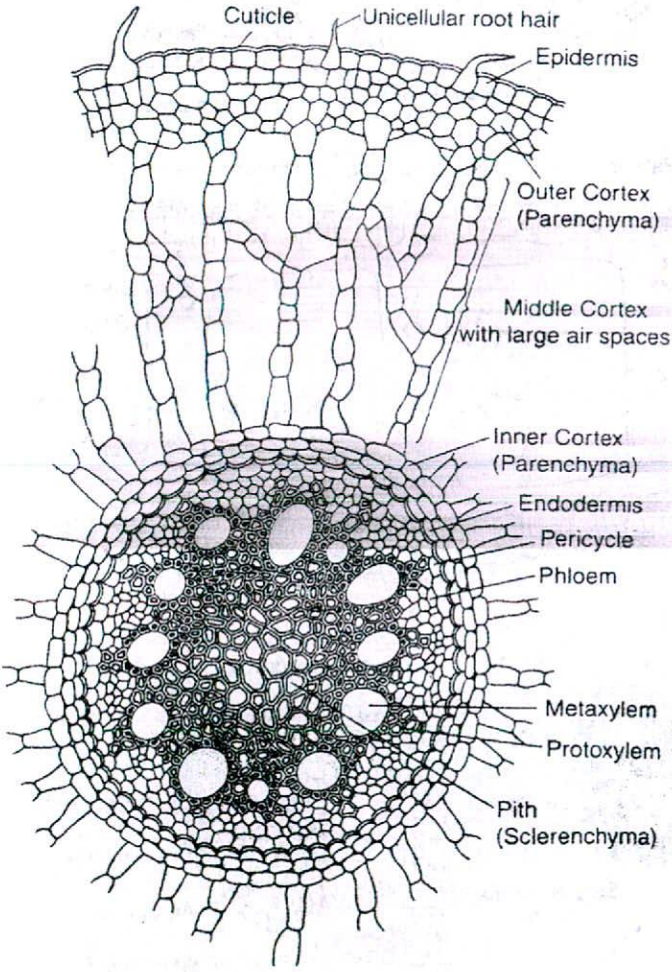

Fig. 8.15. T.S. of root of *Typha latifolia* (monocotyledonous) showing air spaces in cortical region and sclerenchymatous pith.

Phloem tissue is also poorly defined in most of the aquatic plants but in some cases it may develop fairly well. Sieve tubes of aquatic plants are smaller than those of mesophytes. Phloem parenchyma is extensively developed. *Endodermis* may or may not be clearly defined.

The *Vascular bundles* are generally aggregated towards the centre. *Secondary growth* in thickness does not take place in the aquatic stem and roots.

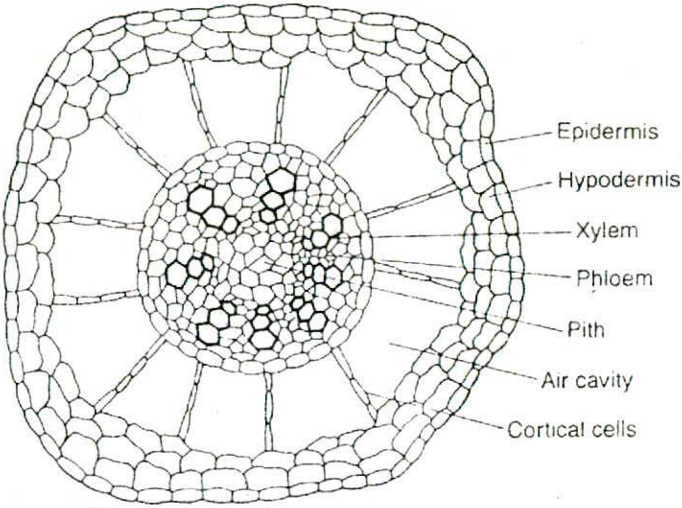

Fig. 8.16. T.S. of stem of *Jussiaea*.

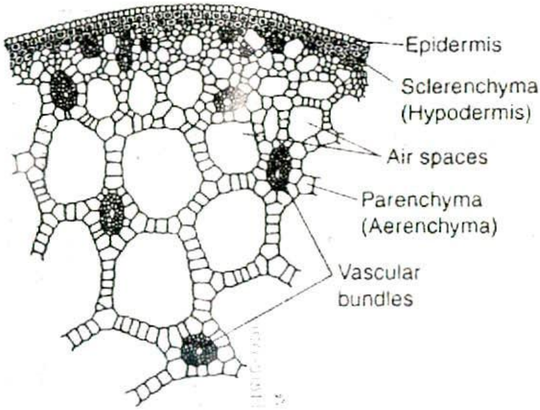

Fig. 8.17. T.S. of petiole of *Eichhornia*.

Distinctive features of different groups of hydrophytes are summarised in the following chart.

Submerged plants 1	*Floating plants* 2	*Amphibious plants* 3
1. Entire surface of plant body remains in direct contact with water.	1. Some parts of the plants are in contact with water and some float on or above the surface of water.	1. Some parts of the plant body grow in water while some others above the surface of water or even on the land.
2. Leaves take CO_2 and oxygen form water.	2. These plants take CO_2 and oxygen partly from air and partly from water.	2. Generally the leaves absorb CO_2 and oxygen from the air because they are well exposed and the exchange of gases can take place very easily through stomata.
3. Heterophylly is not so common.	3. Heterophylly may develop in these plants.	3. Heterophylly is very common.
4. Leaves are greatly reduced in size. They may be ribbon shaped, thin and sometimes very finely dissected.	4. Submerged leaves in the floating plants are thin, ribbon shaped, entire or dissected but those floating on the surface of water are well expanded and entire.	4. Leaves are large, entire, tough and laminae or leaflets are found much above the surface of water.
5. Cuticle, suberin and epidermal hairs are not at all developed. Epidermis acts as absorptive surface rather than a protecting layer. A thin layer of mucilage may be present on the surface.	5. Surface of plant body is coated with a thin film of wax which protects the plant tissue from injurious effects of water and it also prevents clogging of stomata.	5. Cuticle develops on the aerial parts of the plants.
6. Stomata are absent or rarely present in very reduced stage.	6. Stomata are confined only to the upper surface of floating leaves.	6. Stomata are confined to both the upper and lower surfaces of the aerial leaves.

Submerged plants *1*	*Floating plants* 2	*Amphibious plants* *3*
7. Mesophyll tissue is in the form of aerenchyma enclosing large air chambers. Palisade and spongy parenchyma are not very well differentiated.	7. Palisade cells are less developed and spongy tissue is aerenchyma.	7. Mesophyll shows clear differentiation into spongy and palisade tissues. Spongy parenchyma is very well developed with large air passages and diaphragms.
8. Stems are very slender and much reduced. They creep on the substratum either in the form of rhizomes or runners. The stem shows poorly developed vascular bundles. Aerenchyma is very well developed and air chambers are separated by cross septa or diaphragms.	8. Stem is well developed and the fibrovascular system is very much reduced, aerenchyma develops in abundance and air chambers are quite large.	8. Stem is extensively developed but in some, it may be reduced to rhizome. It shows clear differentiation of epidermis, cortex and stelar or vascular zones. Cortex in some cases is differentiated into distinct zones. Outer cortex is aerenchymatous enclosing a number of big air spaces. Inner cortex and pith may be formed of thick walled cells.
9. Roots in submerged plants are greatly reduced, unbranched and without root hairs. They act simply as an anchorage organs. The root system shows poor internal organisation.	9. In some, root is absent while in others, it may be fully developed. Root hairs in free floating plants lie at right angles to the axis of main root. Some roots may be modified into floats, *e.g.*, in *Jussiaea*. Roots show poor differentiation of internal tissues. It functions as absorbing as well as anchorage organ.	9. Roots in amphibious plants are well developed. They show proper differentiation of all internal tissues. Root hairs develop on the epidermis.

Physiological Adaptations in Hydrophytes

The aquatic plants exhibit a low compensation point and low osmotic concentration of cell sap. Osmotic concentration of cell sap is equal or slightly higher than that of water. Nutrients are absorbed by the submerged plants through the general plant surface. The gases are exchanged from the water through the surface cells. The gases produced during photosynthesis

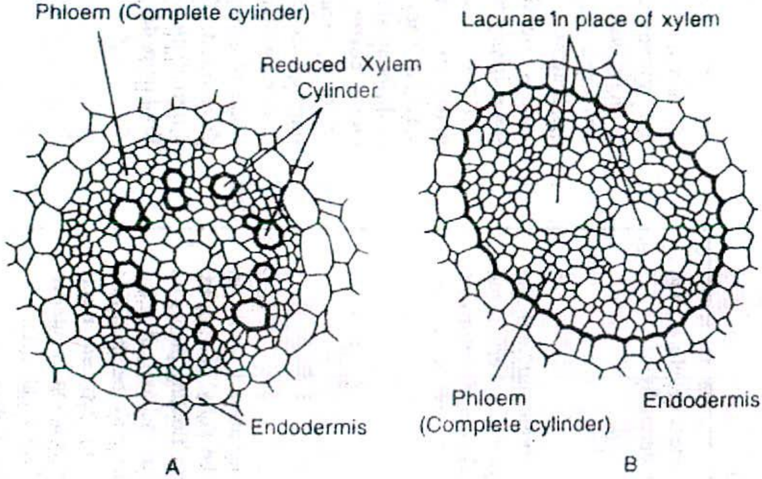

Fig. 8.18. Structure of hydrophytes. A, T.S. of stele of the stem of *Elatine alsinastrum;* B, T.S. of stele of the stem of *Potamogeton pectinatus.*

and respiration are partly retained in the air chambers of aerenchyma to be utilized as and when required. There is no transpiration from the submerged hydrophytes. However, emergent plants and free floating hydrophytes have excessive rate of transpiration. Mucilage cells and mucilage canals secrete mucilage to protect the plant body from decay under water.

XEROPHYTES

Plants which grow in dry habitats or xeric conditions are called xerophytes. Places where available water is not present in adequate quantity are termed xeric habitats. Xeric habitats may be of following types :

1. Habitats physically dry (where water retaining capacity of the soil is very low and the climate is dry, *e.g.*, desert, rock surface, waste land, etc.).

2. Habitats physiologically dry (places where water is present in excess amount but it is not such as can be absorbed by the plants easily. Such habitats may be either too salty or too acidic, too hot or too cold).

3. Habitats dry physically as well as physiologically, *e.g.*, slopes of mountains.

Xerophytes are characteristic plants of desert and semidesert regions, yet they can grow in mesophytic conditions where available water is in sufficient quantity. These plants can withstand extreme dry conditions, low humidity and high temperature. When growing under unfavourable conditions, these plants develop special structural and physiological characteristics which aim mainly at the following objectives :

(*i*) to absorb as much water as they can get from the surroundings;

(*ii*) to retain water in their organs for very long time;

(*iii*) to reduce the transpiration rate to minimum; and

(*iv*) to check high consumption of water.

Xerophytes are categorised into several groups according to their drought resisting power. These groups are as follows :

1. **Drought escaping plants.** These xerophytes are shortlived. During critical dry periods, they survive in the form of seeds and fruits which have hard and resistant seedcoats and pericarps respectively. At the advent of favourable conditions (which are of very short duration), the seeds germinate into new small sized plants which complete their life cycles within a few weeks time. The seeds become mature before the dry condition approaches. In this way, plants remain unaffected by extreme conditions. These are called *ephemerals* or drought evaders or drought escapers. These plants are very common in the semiarid zones where rainy season is of short duration. Examples—*Astragalus* (Papilionatae), some inconspicuous compositae (*e.g., Artemesia*) and members of families Zygophyllaceae, Boraginaceae, some grasses etc.

2. **Drought enduring plants.** These are small sized plants which have capacity to endure or tolerate drought.

3. **Drought resistant plants.** These plants develop certain adaptive features in them through which they can resist extreme droughts.

Xerophytes grow on a variety of habitats. Some grow on rocky soils (Lithophytes), some in deserts, some on the sand and gravels (Psammophytes) and some may grow on the waste lands (Eremophytes). Some plants of xeric habitat have water storing fishy organs, while some do not develop such structures. On this ground xerophytes can be divided into two groups which are as follows :

(1) Succulent xerophytes.

(2) Non-succulents, also called true xerophytes.

Succulent xerophytes are those plants in which some organs become swollen and fleshy due to active accumulation of water in them or in other words, the bulk of the plant body is composed of water storing tissues. Water stored in these tissues is consumed up during the period of extreme drought when the soil becomes depleted of available water.

Xerophytic Adaptations

Plants growing in the dry habitats develop certain structural devices in them. These structural modifications in xerophytic plants may be of two types.

(*i*) **Xeromorphic characters.** Xerophytic characters that are genetically fixed and inherited are referred to as xeromorphic. They will appear in the xerophytes irrespective of conditions whether they are growing in deserts or in humid regions. Halophytic mangroves and many other evergreen trees, although growing in moist conditions always develop xeromorphic characters.

(*ii*) **Xeroplastic characters.** These features are induced by droughts and are always associated with dry conditions. They are never inherited. These characters may disappear from plants if all the favourable conditions are made available to them. Important xerophytic features are summarised under the following heads :

(1) Morphological (external) adaptations;

(2) Anatomical (internal) adaptations;

(3) Physiological adaptations.

1. External Morphology of Xerophytes

(A) Roots. Xerophytes have well developed root systems which may be profusely branched. It is extensive and more elaborate than shoot system. Many desert plants develop superficial root system where the supply of water is restricted to surface layer of the earth. The roots of perennial xerophytes grow very deep in the earth and reach the layers where water is available in plenty. Root hairs are densely developed near the growing tips of the rootlets. These enable the roots to absorb sufficient quantity of water.

(B) Stem. Some of the important characteristics of xerophytic stems are listed below :

(*i*) Stems of some xerophytes become very hard and woody. It may be either aerial or subterranean.

(*ii*) They are covered with thick coating of wax and silica as in *Equisetum*. Some may be covered with dense hairs as is *Calotropis*.

(*iii*) In some xerophytes, stems may be modified into thorns, *e.g.*, *Duranta, Ulex,* etc. (Fig. 8.19).

(*iv*) In stem succulents, main stem itself becomes bulbous and fleshy and it seems as if leaves in these plants are arising directly from the top of the roots. Example—*Kleinia articulata.*

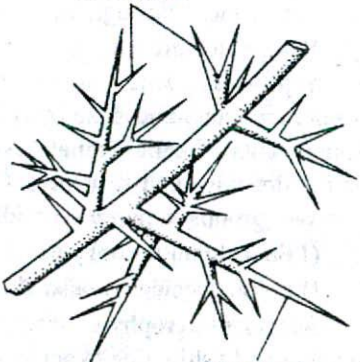

Fig. 8.19. *Ulex* Stem.

(*v*) Stems in some extreme xerophytes are modified into leaf-like flattened, green and fleshy structures which are termed as phylloclades. Many cacti (Fig. 8.23A, B) and cocoloba (*Muehlenbeckia*) (Fig. 8.20 A) are familiar examples for this. In *Ruscus* plants, the branches developing in the axils of scaly leaves become metamorphosed into leaf like structures, the phylloclades or cladophylls (Fig. 8.20 B). In *Asparagus* plant (Fig. 8.20 C) also a number of axillary branches become modified into small needle-like green structures which look exactly like leaves. They are called cladodes. A number of species of *Euphorbia* also develop succulence and become green. In these plants, leaves are greatly reduced, so the main

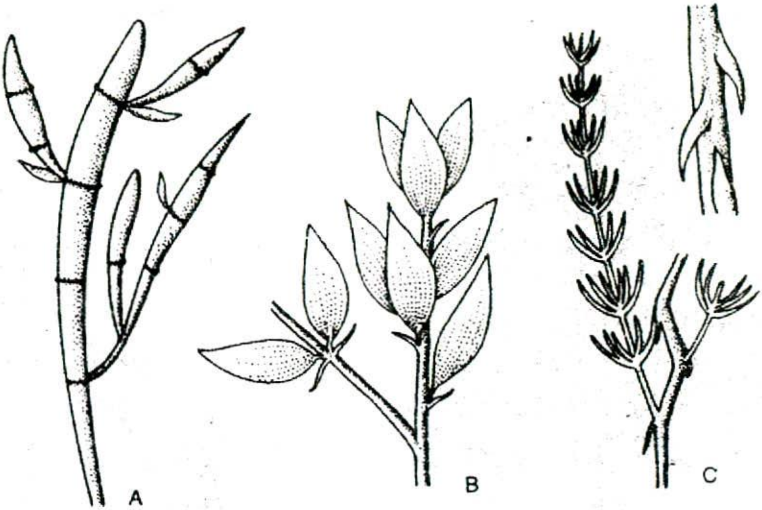

Fig. 8.20. A, B & C—Phylloclade and cladodes. A—Phylloclade of *Cocoloba*. B—Cladodes of *Ruscus*. C—Cladodes of *Asparagus*.

function of leaves, the photosynthesis, is taken up by these green phylloclades or cladodes which are modified stems.

(G) Leaves (*i*) In some xerophytes the leaves, if present, are greatly caducous, *i.e.*, they fall early in the season, but in the majority of the plants leaves are generally reduced to scales, as in *Casuarina* (Fig. 8.21), *Ruscus* (Fig. 8.20 B), *Asparagus* (Fig. 8.20 C), etc.

(*ii*) Some evergreen xerophytes have needle-shaped leaves, *e.g.*, *Pinus* (Fig. 8.22 A, B).

(*iii*) In leaf succulents, the leaves swell remarkably and become very fleshy owing to storage of excess amount of water and latex in them. Plants with succulent leaves generally develop very reduced stems. Examples of leaf succulents are *Sedum acre, Aloe spinossissima* (Gheekwar) (Fig. 8.23 C), *Mesembryanthemum, Kleinia ficoides* and several members of family Chaenopodiaceae.

(*iv*) In majority of xerophytes, leaves are generally much reduced and are provided with thick cuticle and dense coating of wax or silica. Sometimes they may be reduced to spines, as for example, in *Ulex, Opuntia, Euphorbia splendens* (Fig. 8.23 A, B), *Capparis* (Fig. 8.24 B) and *Acacia* (Fig. 8.24D).

(*v*) Generally, the leaves of xerophytic species possess reduced leaf blades or pinnae and have very dense network of veins. In Australian species of *Acacia* (Babool) the pinnae are shed from the rachis and the green petiole swells and becomes flattened taking the shape of leaf. This modified petiole is termed as phyllode (Fig. 8.25). The phyllode greatly reduces the water loss, stores excess amount of water and performs photosynthesis.

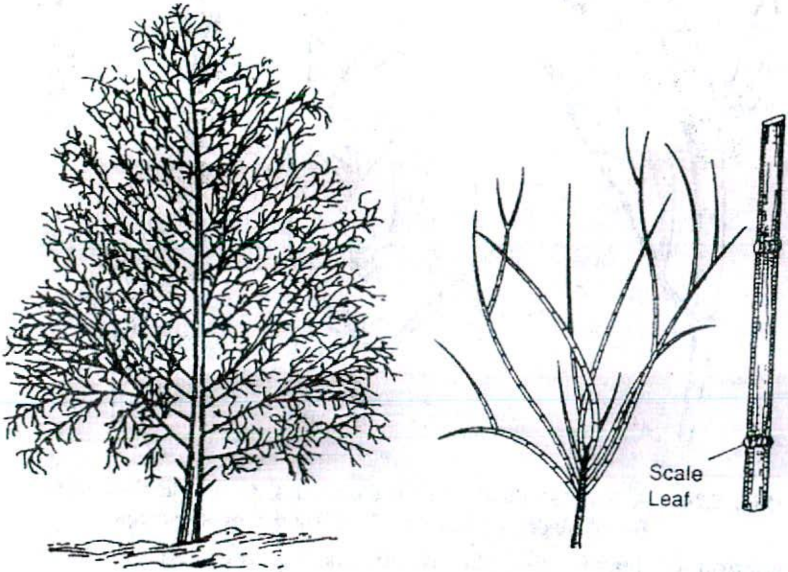

Fig. 8.21. *Casuarina.*

(*vi*) ***Trichophylly.*** In some xerophytes especially those growing well exposed to strong wind, the under surfaces of the leaves are covered with thick hairs which protect the stomatal guard cells and also check the transpiration. Those xerophytes which have hairy covering on the leaves and stems are known as *trichophyllous plants. Zizyphus* (Fig. 8.24 C), *Nerium, Calotropis procera* (Fig. 8.24 A) are important examples.

(*vii*) ***Rolling of leaves.*** Leaves in some extreme xerophytic grasses have capacity for rolling or folding. In these cases stomata are scattered only on the upper or ventral surface and as the leaves roll upwardly, stomata are effectively shut away from the outside atmosphere. This is effective modification in these plants for reducing the water loss. Sundune grass is an important example for this (Fig. 8.27).

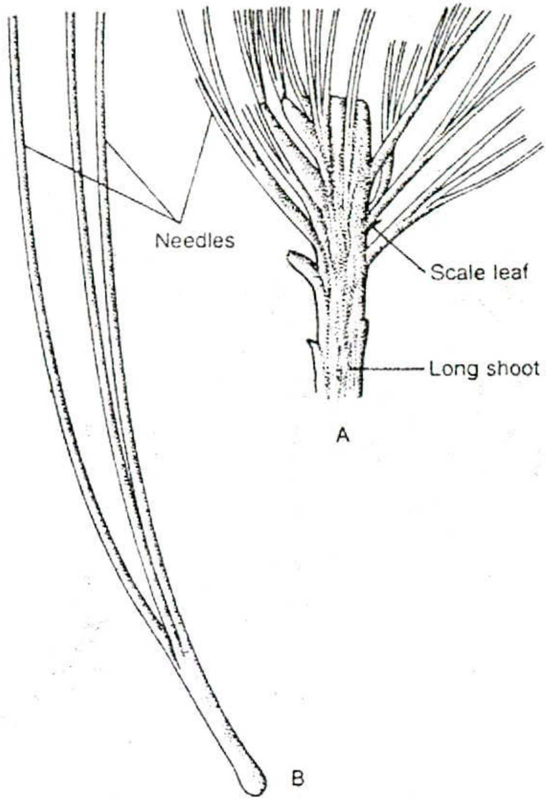

Fig. 8.22. A, B—Long and dwarf shoots of *Pinus roxburghi* showing needle-like leaves and scales.

(D) Flowers, fruits and seeds. Flowers usually develop in the favourable conditions. Fruits and seeds are protected by very hard shells or coatings.

2. Anatomical Modifications in the Xerophytes

A number of modifications develop internally in the xeric plants and all aim principally at water economy. The following are the anatomical peculiarities met within xerophytes :

(*i*) Heavy cutinisation, lignification and wax deposition on the surface of epidermis (Fig. 8.26) and even in the hypodermis are very common in xerophytes. Some plants secrete wax in small quantity but some are regular source of commercial wax. Shining smooth surface of cuticle reflects the rays of light and does not allow them to go deep into the plant tissues. Thus, it checks the heavy loss of water.

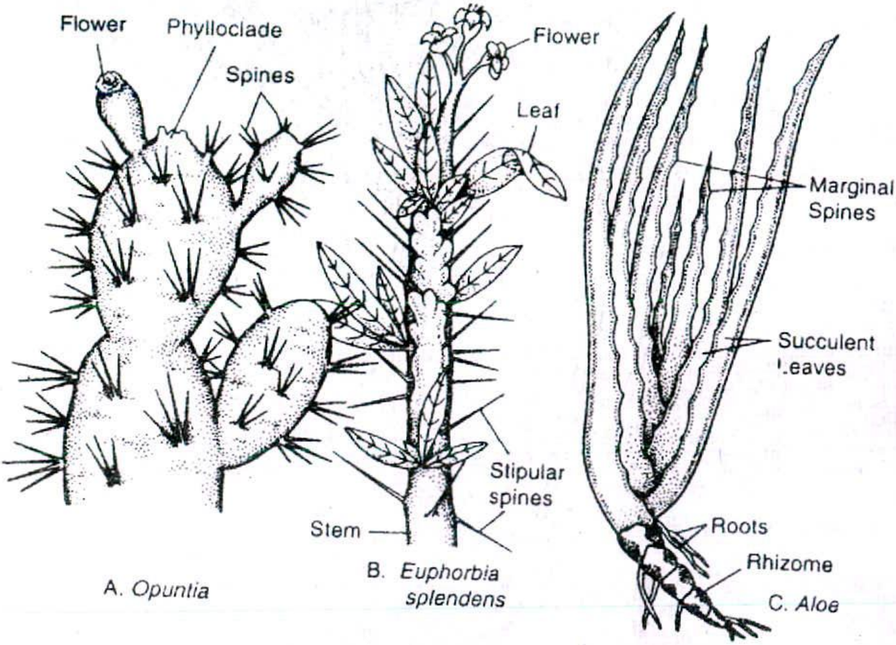

Fig. 8.23 Some succulent xerophytes.

(*ii*) **Epidermis.** Cells are small and compact. It is single layered, but multiple epidermis is not uncommom. In *Nerium* leaf, epidermis is two or three layered (Fig. 8.26). In stems, the epidermal cells are radially elongated. Wax, tannin, resin, cellulose, etc., deposited on the surface of epidermis form screen against high intensity of light. This further reduces the evaporation of water from the surface of plant body. Certain grasses with rolling leaves have specialized epidermis (Figs. 8.27, 8.28). In these, some of the epidermal cells that are found in the depressions become more enlarged than those found in the ridges. These enlarged cells are thin walled and are called **bulliform cells** or **motor cells** or **hinge cells**. These are found usually on the upper surface of leaves between two parallel running vascular bundles. The highly specialized motor cells facilitate the rolling of leaves by becoming flaccid during dry periods. In moist conditions these cells regain their normal turgidity which causes unrolling of the leaf margins. Bulliform cells are of common occurrence in the leaf epidermis of sugarcane, bamboo, *Typha* and a number of other grasses.

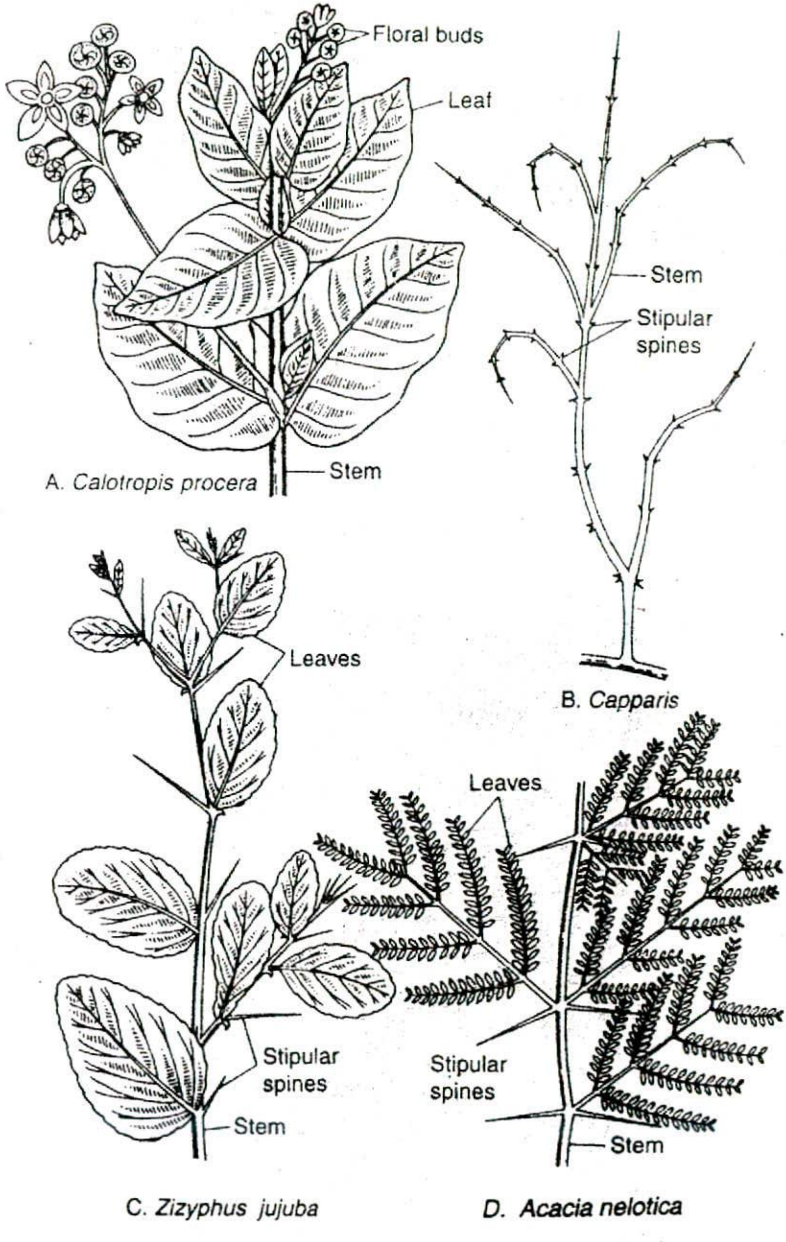

Fig. 8.24. Some common true xerophytes.

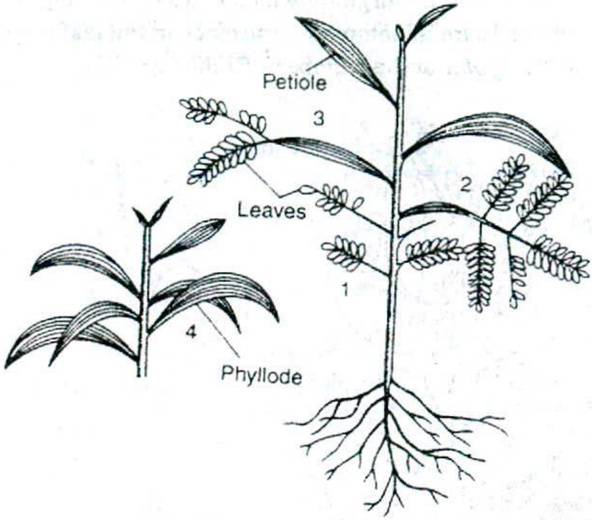

Fig. 8.25. *Acacia* phyllode. Figs. 1, 2, 3 and 4 show the gradual loss of pinnae and development of phyllodes.

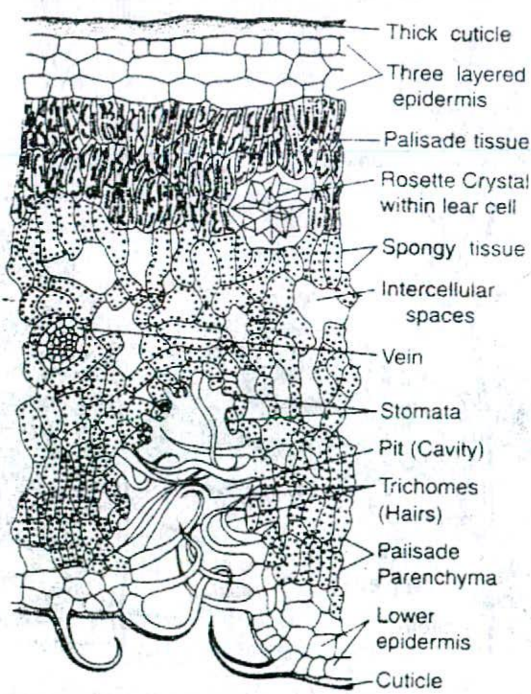

Fig. 8.26. T.S. of *Nerium* leaf lamina showing multilayered epidermis, compact mesophyll and hairy stomatal pit.

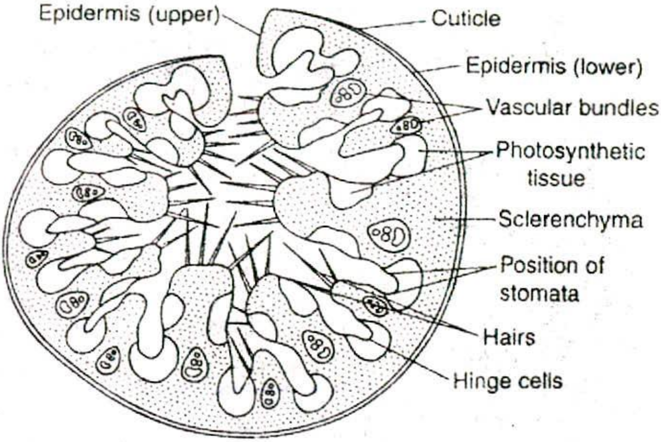

Fig. 8.27. Structure of xerophytic leaf. T.S. (diagrammatic) of *Ammophila arenaria* leaf showing protected stomata.

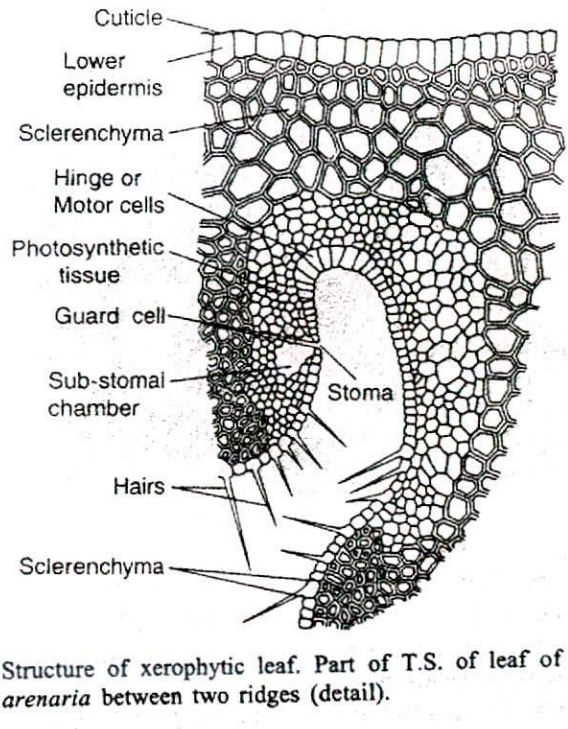

Fig. 8.28. Structure of xerophytic leaf. Part of T.S. of leaf of *Ammophila arenaria* between two ridges (detail).

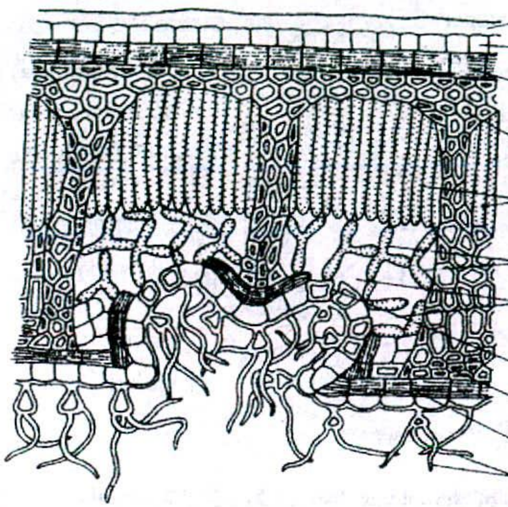

Fig. 8.29. Anatomy of xerophytic leaf. T.S. of *Banksia* leaf (sclerophyllous type).

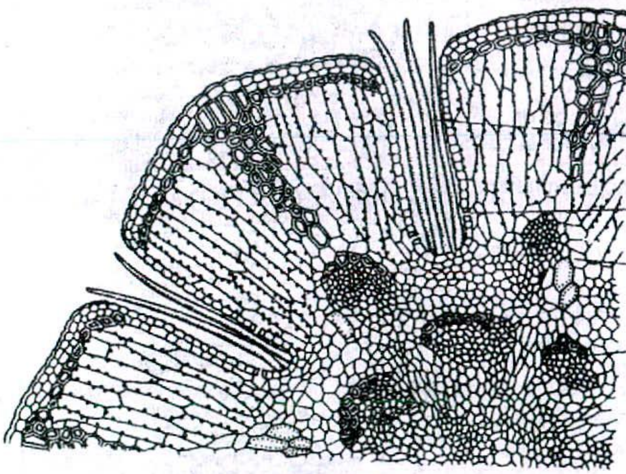

Fig. 8.30. T.S. of *Casuarina* stem.

(*iii*) **Hairs.** Hairs are epidermal in origin. They may be simple or compound, uni- or multicellular. Compound hairs are branched at the nodes. These hairs protect the stomata and prevent excessive water loss. In some plants, surfaces of stems and leaves develop characteristic ridges and furrows or pits. The furrows and pits in these plants are the common sites of stomata. Hairs found in these depressions protect the stomata from the direct strokes of strong wind (Figs. 8.29, 8.30).

(*iv*) **Stomata.** In xerophytes, reduction of transpiration is of utmost importance. It is possible only if the stomatal number per unit area is reduced or if the stomata are elaborately modified in their structures. In xerophytes, number of stomata per unit area of leaf is greater than in mesophytes. They are generally of sunken type. In some cases, they may be found in the furrows or pits. Subsidiary cells of sunken stoma may be of such shapes and arrangement that they form an outer chamber that is connected by narrow opening of the stoma. Such type of specialised stomata are very common in conifers, *Cycas, Equisetum*, etc. (Fig. 8.31). Walls of the guard cells and subsidiary cells are heavily cutinised and lignified in many xeric plants. These devices have little value in directly reducing transpiration when stomata are open. When the plants are wilting and stomata are closed then only lignified or cuticularized walls of guard cells have protecting properties and under such circumstances only cuticular transpiration is possible which is of little significance. In dorsiventral leaves stomata are generally found on the lower surface, but in rolling leaves they are scattered mostly on the upper surface. In the rolled leaves, stomata are protected from the direct contact of outside wind. This is very important rather secured device for lowering the rate of transpiration in xerophytic grasses.

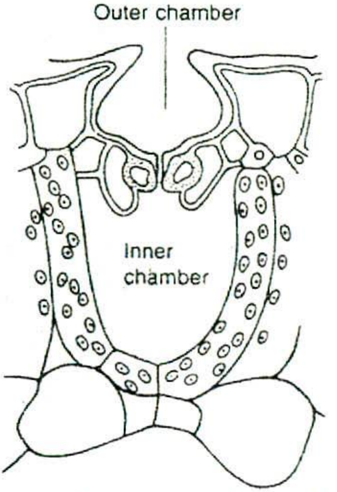

Fig. 8.31. A magnified sunken stoma.

(*v*) **Hypodermis.** In xerophytes, just below the epidermis, one or several layers of thick walled compactly grouped cells may develop that form the hypodermis. The cells may be much like those of epidermis and may either be derived from epidermis or from the cortex (in case of stem) or from the mesophyll (in case of leaf). The hypodermal cells may sometimes be filled with tannin and mucilage.

(*vi*) **Ground tissue.** (*a*) In the stem, a great part of body is formed of sclerenchyma. In those cases, where the leaves are either greatly reduced or they fall in the early season, the photosynthetic activity is taken up by outer chlorenchymatous cortex (Fig. 8.32). The chlorenchymatous tissue is connected with the outside atmosphere through stomata. The gaseous exchange takes place in regular manner in the green part of stem.

(*b*) In succulent stems and leaves, ground tissues are filled with thin walled parenchymatous cells which store excess quantity of water, mucilage, latex, etc. This makes the stems swollen and fleshy (Figs. 8.33, 8.34).

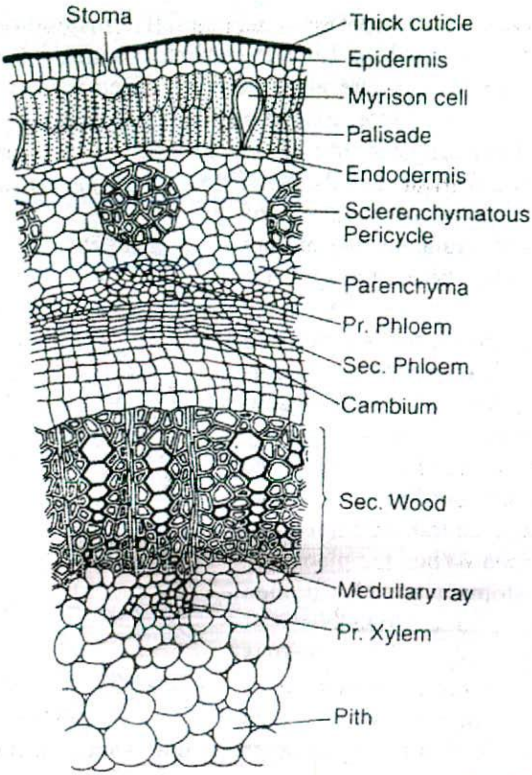

Fig. 8.32. T.S. of *Capparis* stem.

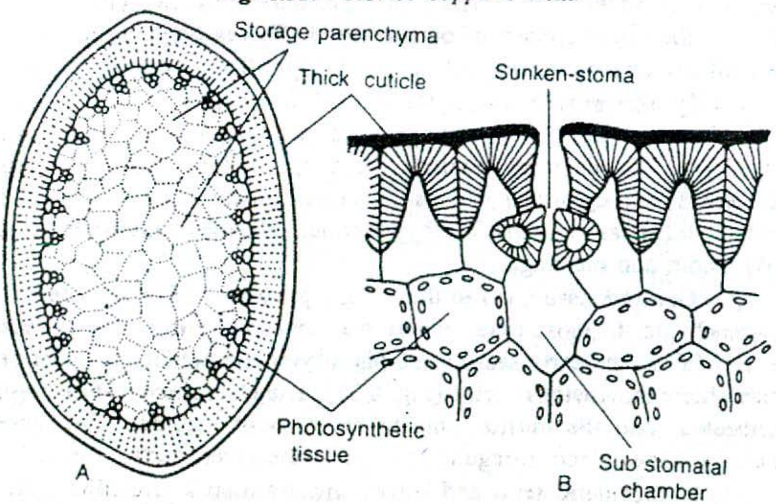

Fig. 8.33. Anatomy of xerophytic leaf—*Aloe* (monocot). A—T.S. of leaf (diagrammatic); B—a portion showing thick cuticle, epidermal cells and sunken stomata.

(*c*) In the leaves, mesophyll is very compact and the intercellular spaces are greatly reduced. Palisade tissue develops in several layers. There are some xerophytes in which mesophyll is surrounded by thick hypodermal sheath of sclerenchyma from all the sides except from below. This sheath forms a diaphragm against intense light. Such xerophytes in which sclerenchyma is extensively developed are called **sclerophyllous** plants. In succulent leaves, spongy parenchyma develops extensively which stores water (Figs. 8.33, 8.34). In *Pinus*, the spongy cells of mesophylls are star shaped (Fig. 8.36).

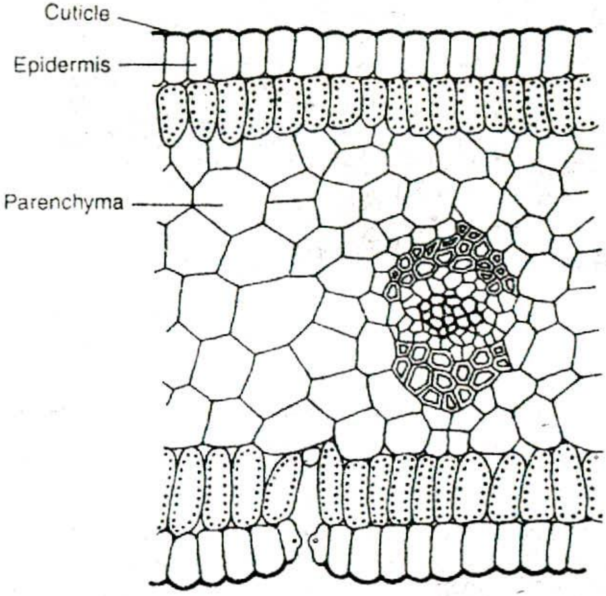

Fig. 8.34. T.S. of *Agave* leaf showing water storing parenchyma.

(*d*) Intercellular spaces are greatly reduced. Cells in the body are generally very small, thick walled and compactly grouped. They may be spherical, rounded or cuboid in shape. Such cells are very common in xerophytes. (Fig. 8.35).

(*vii*) **Conducting tissues.** Conducting tissues, *i.e.*, xylem and phloem, develop very well in the xerophytic body.

3. Physiological Adaptations

It was long assumed that the structural adaptations in the body of xerophytes were useful in reducing the transpiration but now a number of experiments related with the physiology of these plants reveal some facts which are contrary to the early assumptions. Works of Maximov support that except succulents, true xerophytes show very high rate of transpiration. Under similar conditions, the rate of transpiration per unit area in xerophytes is much higher than that of mesophyte. Stomatal frequency per unit area cf leaf surface in xerophytes is also greater than that in the mesophytic leaf.

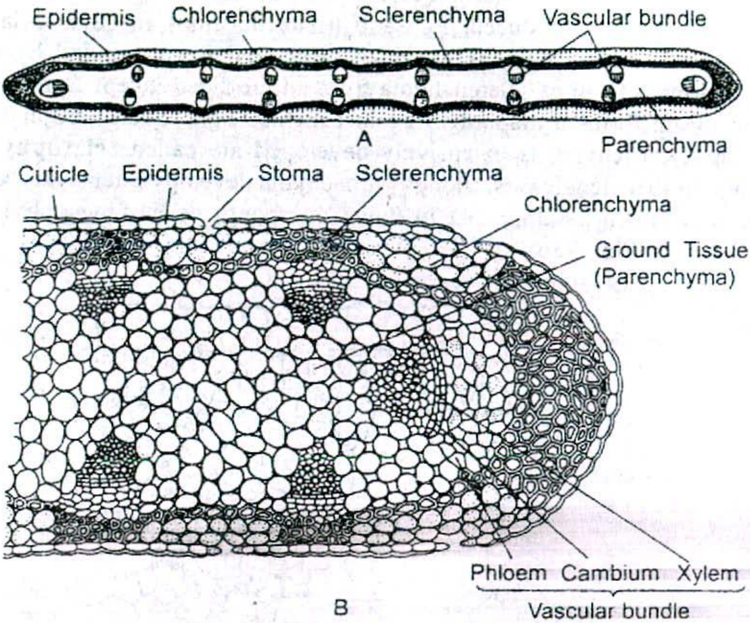

Fig. 8.35. *Homalocladium platycladum* (*Muehlenbeckia platycladus*)—phylloclade (dicot); A—transection of phylloclade (diagrammatic; B,—transection of phylloclade showing detail structure. The stomata, the cambium, the vascular bundles, the scler...chyma and the chlorophyllous cells are clearly visible.

(1) Succulents are well known to contain polysaccharides, pentosans and a number of acids by virtue of which they are able to resist drought. The structural modifications in these succulent xerophytes are directly governed by their physiology. How does the succulence develop? Metabolic reaction which induces development of succulence is the conversion of polysaccharides into pentosans. Pentosans have water binding property. These pentosans together with nitrogenous compounds of the cytoplasm cause accumulation of excess amount of water in the cells and consequently the succulence develops.

(2) Another experimented fact in the physiology of succulent plants is that their stomata open during night hours and remain closed during the day. This unusual feature is associated with metabolic activity of these plants. In dark, these plants respire and produce acids. The heavy accumulation of acids in the guard cells increases osmotic concentration which, in turn, causes inward flow of water in the guard cells. When guard cells become turgid the stomata open. In the sunlight, acids dissociate to produce carbon dioxide which is used up in the photosynthesis and as a result of this osmotic concentration of cell sap decreases which ultimately causes closure of stomata.

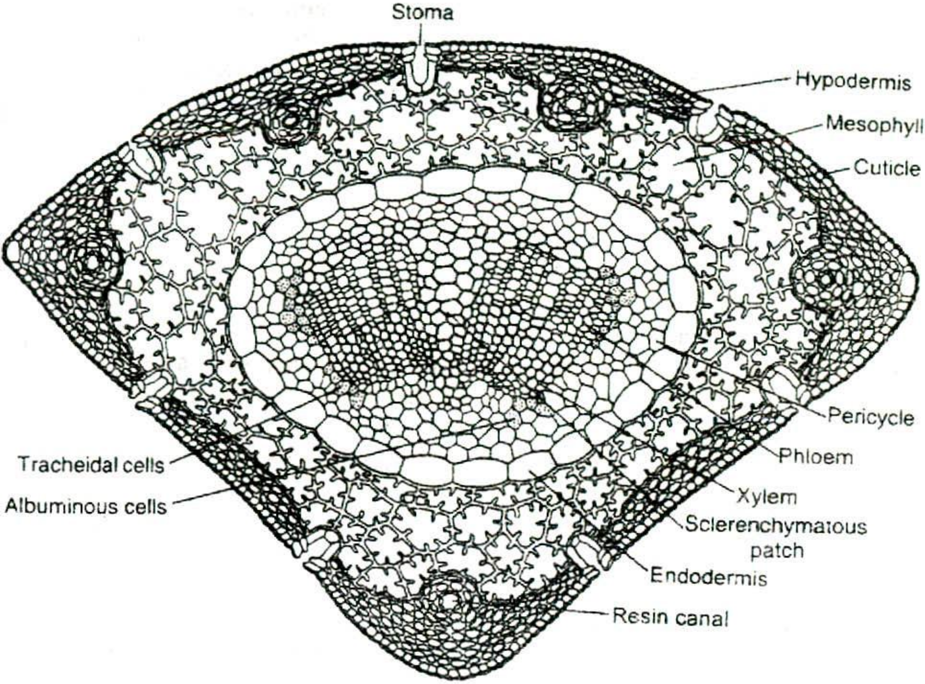

Fig. 8.36. T.S. of *Pinus* needle.

(3) In xerophytes, the chemical compounds of cell sap are actively converted into wall forming compounds that are finally incorporated into the cell walls. Conversion of polysaccharides into anhydrous forms as cellulose, formation of suberin, etc., are some examples.

(4) Some enzymes, such as catalases, peroxidases, are more active in xerophytes than in mesophytes. In xerophytes, amylase enzyme hydrolyses the starch very actively.

(5) The capacity of xerophytes to survive during period of drought lies not only in the structural features but also in the resistance of the hardened protoplasm to heat and desiccation.

(6) **Regulation of transpiration.** Presence of the cuticle, polished surface, compact cells and sunken stomata protected by stomatal hairs regulate the transpiration.

(7) **High osmotic pressure of cell sap.** The xerophytes have very high osmotic pressure which increases the turgidity. The turgidity of cell sap exerts tension force on the cell walls. In this way, wilting of cell is prevented. High osmotic pressure of cell sap also affects the absorption of water.

MESOPHYTES

Mesophytes are common land plants which grow in situations that are neither too wet nor too dry. These plants can neither grow in water or water-logged soils nor can they survive in dry places. In other words, mesophytes are the plants of those regions where climates and soils are favourable. Vegetations of forests, meadows and cultivated fields belong to this category. The simplest mesophytic community comprises the grasses and herbs, richer communities have herbs and bushes, and the richest ones have trees (rainforest in tropics).

Mesophytes can be classified into two main community groups :

(1) Communities of grasses and herbs.

(2) Communities of woody plants.

1. Communities of Grasses and Herbs

These include annual or perennial grasses and herbs. The grasslands occur in area of approximately 25 to 75 cm rainfall per annum. They occur over large interior areas in many countries of the world such as U.S.A., Canada, Australia, Southern Russia, Africa, India. The different types of grasslands and herb communities are listed below.

(*i*) **Arctic and alpine mat-grasslands and mat-herbage.** Such communities are restricted to polar regions and mountain tops. The plants are small sized soft shrubs, and the under-shrubs are totally absent. Mosses may be intermingled but lichens do not appear. This groups is subdivided into two :

(*a*) Mat grassland (Gramineae)

(*b*) Mat herbage (Dicotyledonous herbs such as *Saxifraga, Delphinium, Potentilla, Ranunculus,* etc.).

(*ii*) **Meadow.** This forms a connecting link between mesophytes and hydrophytes as they grow in soils where moisture is 60—83%. Plants are tall perennial herbs with long stems. Soil is invisible due to overcrowding of plants. Plants are mostly rhizomatous. The leaves show mesophytic features, *i.e.,* they are thin, broad, flat and glabrous. Members of families Gramineae, Ranunculaceae, Papilionatae and Compositae are found in abundance.

(*iii*) **Pasture on cultivated land.** Vegetation is shorter and more open than in meadow. It is disturbed very often by grazing. The vegetation usually includes grasses, dicot herbs and some mosses.

2. Communities of Woody Plants (Bushland and Forests)

These are classified and described in the following ways :

(*i*) **Mesophytic bushlands.** Such a mesophytic community occurs where temperature and other conditions are not favourable for the growth of forest but they are too much favourable for mat herbage vegetation. In many places, xerophytic and mesophytic bushlands merge with each other. *Salix, Arabis, Lathyrus, Vicea,* etc., are the important plants of bushlands.

(*ii*) **Deciduous forests.** These forests are found in the areas where rainfall is high enough (about 75—150 cm per year) and evenly distributed and the temperature is moderate. Such forests are characterised by trees which become leafless for certain periods of the year. The foliage persists for about five to eight months. This phenomenon of repeated foliation and defoliation of trees is prominent in temperate and cold regions (where there is long winter) and in tropics as well where the summer is of long duration. Leaves are dorsiventral and they exhibit many shapes and structures. The trees are profusely branched. Mycorrhizae are present on the roots. Epiphytic mosses and lichens grow in abundance on the surface of the trees. The majority of the plants are pollinated by wind. The soil is very rich in microflora. The deciduous forests are named after dominant trees of those particular communities, as for example, *Quercus-Oak* forest, *Betula-Birch* forest, *Fagus-Beach* forest and so on.

Tropophytes (changing plants), an interesting group of tropical plants can be included in this group of mesophytes. Generally in tropical regions, the climate remains, more or less, uniform throughout the year but in some tropics there is alternation between damp and dry cold climates. Plants growing in the tropics of disuniform climate develop some structural modifications through which they can endure the regular cycle of favourable and unfavourable seasons in one way or the other. In other words, tropophytes behave as mesophyte during rainy season and as xerophytes during dry cold season. The shedding of leaves may occur in the beginning of winter season or in the summer. Important adaptive features of these plants are :

(*a*) better protection of winter buds

(*b*) thick bark covering on the stem

(*c*) formation of underground stem which protects the perennating buds from extreme drought and cold. Conifers are the familiar examples of tropophytes.

(*iii*) **Evergreen forests.** These forests are found in the tropical and subtropical regions extending into the cold temperate zones of southern hemisphere. Plants in these forests are evergreen (*i.e.*, they retain their leaves for more than one year until new foliage appears). Very few species in these forests may show leaffall. Evergreen forests are of three types :

(*a*) **Antarctic forests.** These forests cover mountains of New Zealand and a number of other countries in the world where annual temperature ranges from 5°C to 70°C and the rainfall is abundant throughout the year. Important plants found in these forests are conifers, Myrtaceae, Hymenophyllaceae. Mosses and Liverworts may also be present.

(*b*) **Subtropical forests.** These forests are found in the regions of fairly high rainfall but where temperature differences between winter and summer are less marked. Winter generally goes without rains. The plants are about 30 metres in height. These forests include *Oaks, Magnolias, Tamarindus* and mosses. Subtropical forests occur in eastern part of U.S.A., South Brazil, South Africa, East Australia, Southern China, and Japan.

(*c*) **Tropical Rain forests or Tropical Evergreen forests.** Tropical rain forests are found in low lying regions near the equator with annual rainfall of 180 cm or more. This type of forest is most dense and is undisturbed by biotic agencies and is therefore, called "primeval forest". The rain forests represent the climax vegetation of the whole world. Climate of such forest is characterized by :

(1) high humidity (air saturated by 95% humidity)

(2) high temperature

(3) daily rains

(4) no distinct dry season

(5) soil very rich in humus, black in colour, and porous.

The plants show luxuriant growth and they are found in several storeys. Humboldt very appropriately commented "forest is piled upon forest", *i.e.*, highest trees form top layer about 40—50 metres up, beneath which is the storey of short trees, then storey of low palms and trees, ferns, then, storey of scattered and herbs shrubs (4 to 5 metres in height). On the surface of ground may be found *Selaginella,* mosses etc. (Fig. 8.37).

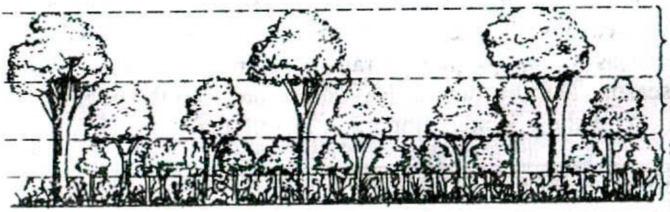

Fig. 8.37. A forest view showing stratification of the plants.

Roots of the plants may be found covered with saprophytes and parasites, *e.g., Rafflesia, Balanophora, Monotrapa* etc. Epiphytes and lianas are very common in these forests. Very dense growth of the shrubs and climbers makes the forests impenetrable. Plants usually acquire tree forms. Most of them produce root buttresses for the support of their huge trunks. They show cauliflory in which the buds are protected by stipules, leaf sheaths and petioles, etc. Flowers are of various colours and they develop high over the heads. Plants do not show periodicity for foliation and flowering. Each species has its own flowering and foliation time. The leaves exhibit almost all shapes and are usually directed upwardly to drain off excess water. The leaf surface is cutinised and impregnated with silica which protects them from violent rains. Leaves may be provided with channelled nerves and dripped tips (*i.e.,* they have long and narrow apices). Trees develop thick barks.

Plants belonging to families Leguminoceae, Lauraceae, Myrtaceae, Moraceae, etc. are very commonly found in tropical rain forests.

Vegetational succession in the tropical rain forest takes place in the following sequence :

The pioneer colonisers are deciduous plants that are replaced gradually by semideciduous vegetation that persists for very short period of time after which semi-evergreen plants make their appearance. The semi-evergreen vegetation becomes intermingled with some evergreen plants which finally become dominant. In this way the climax forests develop. This sequence is possible only if the biotic factors are not allowed to affect the vegetation to a major degree. Tropical rain forests are found in central and southern America, central Africa, Pacific Islands, Malaya and in many other equatorial countries of the world. In India, these forests are found in south-eastern Himalayas, tracts of Assam, and western slopes of Nilgiri.

The tropical rain forests are of great economic values to the human beings. These yield timbers of high quality.

QUESTIONS

1. What are hydrophytes? Describe the various morphological and anatomical adaptations met within hydrophytes.
2. Describe the various features of different groups of hydrophytes. Illustrate your answer with suitable examples.
3. What are xerophytes? Describe the various morphological and physiological adaptations of xerophytes.
4. Describe the main ecological adaptation of plants growing in ponds.
5. Write short notes on the following :
   Succulents, Amphibious plants, Heterophylly, Sclerophylly, Bulliform cells, Trichophylly, Diaphragm.

9

EPIPHYTES

Epiphytes (*Epi* = *above*, *phyton* = plant; *i.e.*, plant growing upon plant) are those autotrophic plants which grow on the surface of some other supporting plants and are not permanently rooted in the soil. Orchids, Bo tree (Pipal tree), some algae, lichens and mosses are some of the familiar examples. These plants absorb sufficient moisture from the atmosphere and mineral nutrients from the decaying bark of the supporting plants upon which they are situated. As they are autotrophic in nutrition, they manufacture their own food (carbohydrates) from water and CO_2 in presence of sunlight. These plants differ from parasites because they do not derive nutrients and water from the living parts of supporting plants, and also they differ from lianas (woody stem climbers) because epiphytes, in the real sense of term, are not permanently rooted in the soil. Epiphytes are also called *Aerophytes* or air plants.

Distribution

Some epiphytes grow on the surface of submerged aquatic plants, while others may be aerial. Some are found growing on the surface of tree trunks, some on the horizontal forks of the trees and some may grow even on the surface of leaves (*i.e.*, epiphyllous epiphytes). Some epiphytes show specificity in selection of their supporting plants. *Tortula pagorum*, an epiphytic moss, is peculiar in the sense that it grows on the tree trunks within the urban limits. This moss grows well in the city atmosphere presumably because it requires high temperature and smoky air for its normal growth. Both these factors are available to the plants in the city area. Some epiphytic species may often grow on rocks, and some may grow rarely even on the poles and horizontal telephone wires.

Epiphytic vegetation is very rich in moist and cold regions but poor in dry and cold areas. In north-western Himalayas the epiphytic species are much less in number as compared to those present in the eastern Himalayas. In warm and wet regions, members of the families Bromeliaceae and Orchidaceae are found in abundance. In tropical rain forests, epiphytic species found at the tops of trees are xerophytic in nature but those occurring at lower levels are hygrophilous (moisture and shade loving).

Important Features

Since the epiphytes depend directly for their water supply on rains, atmospheric moisture, snow and dew, they develop certain structural adaptations for water storage and for reducing excessive water loss. The important features are listed below :

1. Morphological Features

(*i*) **Root system.** In the epiphytic vascular plants, the root system is extensively developed. In these cases, the roots may be of the following three types (Fig. 9.1) :

(*a*) **Normal absorbing roots.** Which absorb water, minerals, and organic nutrients from the moist crevices of decaying barks of supporting plants.

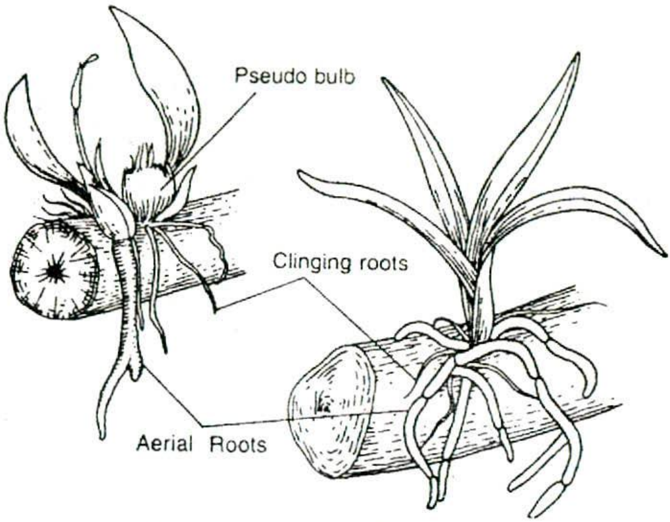

Fig. 9.1. Different types of roots of epiphytes.

(*b*) **Clinging roots.** These roots fix the epiphytes on the surface of the supporting object firmly and also absorb nutrients from the humus and dust that are accumulated on the surface of bark.

(*c*) **Aerial roots.** These are spongy and green roots which hang downwardly in the atmosphere and absorb moisture from the air. These roots can photosynthesize in light because of the presence of green colour in them.

In some epiphytes, the roots collect on their surface good amount of dust that holds water which will finally be absorbed by the roots.

(*ii*) **Stem.** Stem in epiphytic vascular plants may or may not be extensively developed. Some epiphytes develop succulence in their stems and become pseudobulbous or tuberous (Fig. 9.1).

(*iii*) **Leaves.** The majority of epiphytes show considerable reduction in leaf number. Some orchids develop only a single leaf in a growing season. Leaves in some may be fleshy and leathery. In *Dischidia nummularia, Platycerium* and *Asplenium nidus* leaves are modified into the pitchers.

Dischidia nummularia, an epiphytic species of family Asclepiadaceae, growing very commonly in Sunderban shows peculiar types of leaf pitchers. The pitchers have openings through which the adventitious roots enter inside. The roots branch copiously into a number of very delicate rootlets which spread on the entire inner surface of pitcher and form a network (Fig. 9.2). The inner surface of pitcher is coated with wax. Pitcher collects and

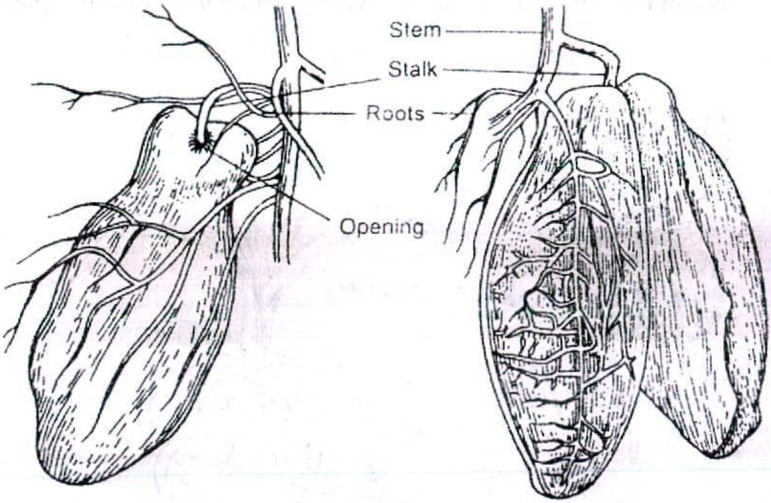

Fig. 9.2. Leaf pitchers of *Dischidia nummularia.* Right pitcher is cut open longitudinally to show network of roots on its inner surface.

accumulates rain water, humus and minerals that are absorbed by the root network. Sometimes ants and insects enter the cavity of the pitcher through hole where they may be killed and digested. The dead remains of animals serve as nitrogen source for the plants. Myrmecophily which is a sort of symbiotic association between ants and plants is of common occurrence in the epiphytic vegetation. In the family Bromeliaceae, some species develop spoon-like leaves in rosettes. These leaves collect and store rain water which is finally absorbed by the epidermal hairs present on the concave surface of the leaves.

***(iv)* Fruits, Seeds and their dispersal.** The fruits and seeds are usually dispersed by wind, insects and birds. When the seeds reach the suitable surface and get favourable environment, they germinate over there and give rise to new independent epiphytes.

2. Anatomical Features

Important anatomical peculiarities in epiphytes are as follows :

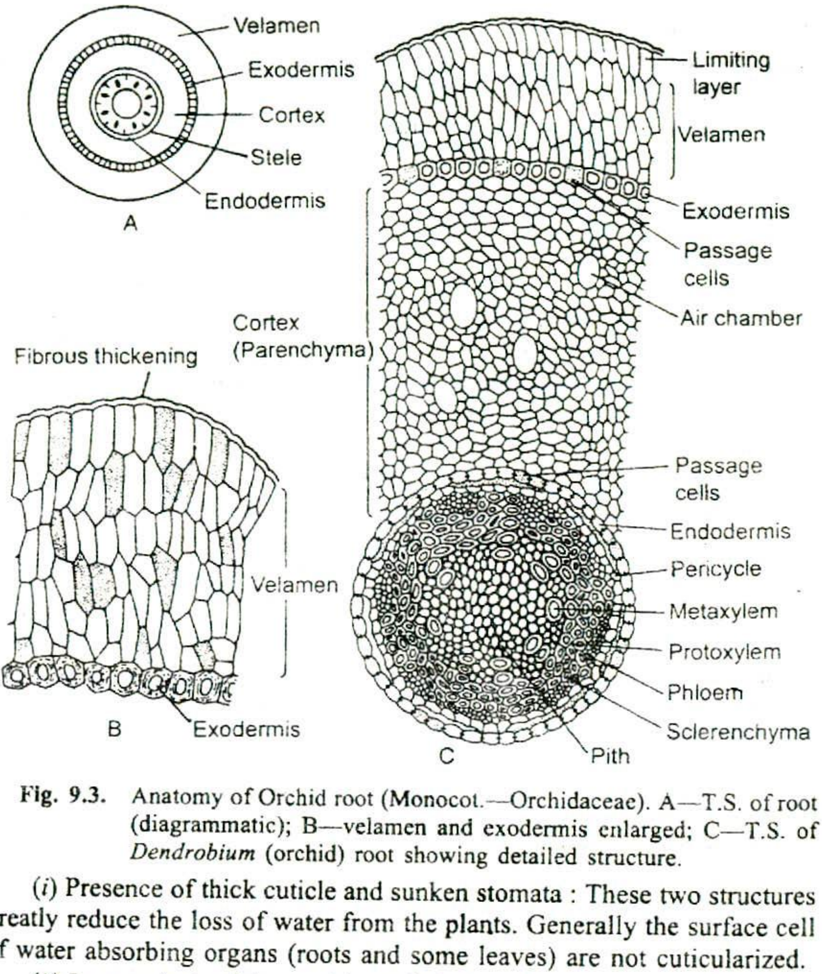

Fig. 9.3. Anatomy of Orchid root (Monocot.—Orchidaceae). A—T.S. of root (diagrammatic); B—velamen and exodermis enlarged; C—T.S. of *Dendrobium* (orchid) root showing detailed structure.

(*i*) Presence of thick cuticle and sunken stomata : These two structures greatly reduce the loss of water from the plants. Generally the surface cell of water absorbing organs (roots and some leaves) are not cuticularized.

(*ii*) In succulent epiphytes, thin-walled parenchymatous tissue that stores water, develops extensively.

(*iii*) The aerial hanging roots of many tropical epiphytes belonging to the families Araceae and Orchidaceae develop on their surface a characteristic greenish white thin-walled massive tissue. That is called velamen (Fig. 9.3). The velamen is hygroscopic tissue that rapidly absorbs moisture from the saturated atmosphere like a sponge. It is modification of multilayered epidermis. Its cells are empty (*i.e.*, dead) and cell walls show spiral or reticulate thickenings. Inner to the velamen there is present a peculiar layer called *'exodermis'*. Exodermal cells are of two types :

(*a*) Lignified and thick-walled cells.

(*b*) Thin-walled cells or passage cells, walls of which are permeable to water. The velamen absorbs and retains moisture till that is absorbed by passage cells of exodermis.

(*iv*) Other structures are similar to those found in mesophytes.

Types of Epiphytes

Schimper has classified epiphytes into four subgroups which are as follows :

(1) **Protoepiphytes.** These plants derive their nourishment partly from the surface of the supporting plants and partly from the atmosphere. They do not develop any adaptive feature in them except perhaps, aerial roots with velamen. Examples : *Peperomia, Dischidia* and some ferns belong to this group.

(2) **Hemiepiphytes.** These plants grow on the supporting plants in the beginning like true epiphytes but later on they establish connection with the soil by their roots. Epiphytic Fig trees, some root climbing Aroids, *Scindapsus officinalis,* etc. are important plants of this group.

Some stem climbing plants grow in the soil but their stems die from below upward and terminal portions live independently like hemiepiphytes. Such plants are termed as Pseudoepiphytes.

(3) **Nest epiphytes.** These plants have appropriate devices to collect large quantity of water and humus for their own use. Orchids are familiar examples of this group.

(4) **Tank epiphytes.** These plants develop fibrous anchoring roots which do not take part in the water absorption. Leaves, that are variously modified, absorb water and manufacture food. *Nidularium, Tillandsia,* and other epiphytic species of Bromeliaceae are common plants of this group.

QUESTIONS

1. What are epiphytes? Describe the various morphological features of epiphytes.
2. Write short notes on :
   (*i*) Velamen
   (*ii*) Root system of epiphytes.

10

HALOPHYTES AND MANGROVE VEGETATION

Some plants grow and complete their life cycle in the habitats with a high salt content. They are known as salt plants or halophytes. According to Stocker (1933), the critical level of salinity for plants is 0.5% of the dry weight. Though the fact that only a small group of higher plants can grow in the saline habitats was recognized many hundred years ago, yet the name "halophyte" was assigned to such plants by Pallas in the early nineteenth century. Such plants are commonly found near sea-shores where mesophytes and fresh water hydrophytes cannot thrive well. Although these plants grow in the areas which are well saturated with water yet they cannot avail of the water because of high concentration of salts in the soils. Thus, the halophytes are plants of physically wet but physiologically dry habitats. Plants cope with the problems of salinity in various ways, some of them avoid salinity, some evade salinity or resist it, and a few others tolerate salinity. Salinity avoidance is usually accomplished by limiting germination, growth and reproduction to specific seasons of the year as well as by growing roots into non-saline layers and limiting salt uptake. Plants evade or resist salinity by accumulating salts in their cells as well as by secretion of excess salts. In the salt tolerants, the protoplasm functions normally and endures a high salt concentration without apparent damage.

Plants occupying only local non-salty ecological niches in an overall saline environment or those which appear in such habitats only for short periods, *i.e.*, during rainy season are called psuedohalophytes or false halophytes (Yoave Waisel, 1972). Saline habitats are not restricted to sea coasts only but they may also be found in many dry places far away from the sea coasts. In India, certain places in Rajasthan and in many other deserted places, the soils are very salty because of presence of sodium chloride, calcium sulphate, sodium bicarbonate, potassium chloride, etc. In these dry and salty habitats generally succulent xerophytes, *e.g.*, *Chaenopodium album*, *Suaeda fructicosa*, *Haloxylon salicorneum*, *Salsola foestida*, *Tamarix articulata* grow very successfully and form microedaphic formations.

Classification of Halophytes

Stocker (1933) proposed first classification of saline habitats which is as follows :

1. Aquatic-haline
2. Terrestro-haline
   (*a*) hygrohaline
   (*b*) mesohaline
   (*c*) xerohaline
3. Aero-haline
   (*a*) Habitats affected by salt spray (maritime)
   (*b*) Habitats affected by salt dust (salt desert)

On the basis of contact between salt and plant in different habitats halophytes can be grouped into the following categories :

1. In terrestrial saline habitat, the contact occurs between the plant roots and soil—*terrestrial halophytes.*
2. In aquatic-haline habitat contact occurs :
   (*a*) between salt and plant roots—*emerged halophytes* or *hygrohalophytes,* and
   (*b*) between salt and entire plant body—*submerged halophytes* or *hydrohalophytes.*
3. In aero-haline habitat, the contact occurs :
   (*a*) between aerial organs of plants and air borne salt droplets (in coastal regions), and
   (*b*) between aerial organs and salt droplets (in dust deserts)—*Aerohalophytes.*

Iversen (1936) classified the haline habitats on the basis of their salt contents. Different habitats and plants found therein are given below :

	Habitat	*Salt content*	*Plants*
1.	Oligohaline	0.01—0.1% NaCl	Oligohalophytes
2.	Mesohaline	0.1—1.0% NaCl	Mesohalophytes
3.	Polyhaline	1% NaCl and up	Euhalophytes

Besides above-mentioned three types of halophytes, there are some other halophytes which grow in habitats with wider salinity ranges. Plants occurring in both oligohaline and mesohaline habitats are called **oligo-mesohalophytes** and those existing in all the three types of habitats are called **euryhalophytes.**

According to Chapman (1942), halophytes have been classified into the following categories :

(*i*) **Miohalophytes**—Plants growing in the habitats of low salinity (below 0.5% NaCl).

(*ii*) **Euhalophytes**—Plants of highly saline habitats. They have been further sub-divided into the following groups :

(*a*) **Mesohalophytes**—Plants of habitats with salinity range of 0.5 to 1%.

(*b*) **Mesoeuhalophytes**—Plants of habitats with salinity range of 5% and higher.

(*c*) **Eneuhalophytes**—Plants of habitats with salinity range of 1% and up.

Van Eijk (1939) classified halophytes into the following two main categories on tne basis of their distribution and their responses to saline habitats.

(*i*) **Salt enduring halophytes** which show optimum development in non-saline habitats but can tolerate salts.

(*ii*) **Salt resistant halophytes** which show optimum development in saline habitats.

Tsopa (1939) classified halophytes in to the following four groups on the basis of their response to salinity.

1. **Obligatory halophytes**—Plants requiring salinity throughout their life.

2. **Preferential halophytes**—Plants show optimum growth in saline habitats, despite their appearance in non-saline habitats.

3. **Supporting halophytes**—Non-aggressive plants which are capable of growing in saline habitats.

4. **Accidental halophytes**—Plants which grow in marsh saline habitats only accidentally. Steiner (1935) classified salt marsh plants into the following three types :

(*a*) **Succulent halophytes**—Plants which can tolerate high concentration of chloride in their cell sap due to increased succulence (as for example, *Salicornia herbacea).*

(*b*) **Non-succulent halophytes**—Plants resisting salts by desalinization of their tissues and secreting excess salts through salt glands (*e.g., Spartina alterniflora*).

(*c*) **Accumulating type**—Plants without any special mechanism of salt removal. Salt concentration in such plants goes on increasing until the death of plants (*e.g., Juncus gerardii, Suaeda fructicosa*).

Coastal angiospermic halophytes have been divided into the following groups :

(*i*) Submerged marine halophytes—*hydrohalophytes,*

(*ii*) Low coast plants—*hygrohalophytes,*

(*a*) *Swamp halophytes,* the **mangrove**, and

(*b*) *Marsh halophytes,*

(*iii*) High coast plant —*aerohalophytes.*

Mangrove is a West Indian name given to formation of trees and shrubs inhabiting the coasts and river estuaries of tropical or subtropical seas. Plants occurring in mangrove vegetation belong to several families.

Common mangrove plants are *Rhizophora mucronata, Kandelia rheedii, Ceriops roxburghiana, Bruguiera gymnorhiza,* and many other plants belonging to the family Rhizophoraceae, *Avicennia offcinalis* of the family verbinaceae, *Acanthus ilicifolius,* (Acanthaceae), *Ardesia humiles* and *Aegiceras majus* of family Myrisinaceae, *Cassula species* (a very common plant of rice field in northern India belonging to the family compositae), *Cometes surathensis* (Caryophyllaceae) which is commonly found in western Asia, *Avicennia, Sechium edule* (Aroideae)—an Indomalayan plant, *Cryptaeorine ciliata* (Aroideae)—a common plant growing in the muddy banks of Ganga, *Poa, Festuca, Melacanna, and Oryza patnai* (rice) of family Gramineae, *Scirpodendron* of Cyperaceae and a number of other plants belonging to the families Palmae, Parkeriaceae Chaenopodiaceae, Plumbaginanceae, Ficoideae, Euphorbiaceae.

Mangrove plants are very commonly found on some saline soils of Indogangetic plains (Bay of Bengal, Sunderbun and Assam), in western India near the sea coasts of Mumbai and Kerala, in the banks of **Gaumati** and Godavari in south India,, particularly in the regions where rivers meet the ocean, and in Andaman and Nicobar Islands.

Mangrove vegetation of Gangetic estuary, particularly of Sunderbun region, according to Prain, is localized in the following three geographical zones :

1. Southern coastal strip and south-western part,
2. Central zone, and
3. North-eastern part.

The Central zone is characterized by climax forest of *Heritiera. Ceriops* is one of the dominant plant species on the higher grounds near the sea and at certain places it may form pure forest in Sunderbun.

Mangrove vegetation in the western sea coast of India is represented by the following plant communities.

(*i*) *Avicennia alba* and *Avicennia officinalis* community.
(*ii*) *Acanthus ilicifolius* and *Avicennia alba* community.
(*iii*) *Suaeda fructicosa* populations,
(*iv*) Pure community of *Salvadora* species,
(*v*) *Sesuvium portulacastrum* population, and
(*vi*) *Aeluropus repens* population.

Godavari delta in Andhra Pradesh shows characteristic mangrove vegetation of *Avicennia alba, Avicennia marina, Rhizophora, Bruguiera, Ceriops, Sonneratia, Acanthus ilicifolius, Myriostachya weightiana, Clerodendron inerme,* etc.

The ecological conditions which are essential for the development of mangrove vegetation or halophytes are :

(*a*) shallow water with thick mud,
(*b*) water logged saline soil or sandy or loose soil or heavy clays containing large amount of organic matter,

(*c*) high rainfall, and

(*d*) high humidity in the atmosphere and cloudy weather.

Important Characters of Halophytes

As the water in the habitat is not such as can easily be absorbed by the plants, the halophytes develop in them almost all important xerophytic devices for water economy.

1. **Habit.** A great majority of halophytes in the tropical and subtropical regions are shrubs, but a few of them are herbaceous, for example, *Acanthus ilicifolius*. In temperate zones, halophytic vegetation is purely herbaceous.

The shrubs are generally dome-shaped in appearance because of their cymose branching.

2. **External morphology.** (*a*) **Roots** (*i*) Halophytes develop many shallow normal roots. In halophytes, in addition to normal roots, many stilt or prop roots develop from the aerial branches of stem for efficient anchorage in muddy or loose sandy soil. These roots grow downward and enter the deep and tough strata of the soil. In some plants, *e.g.*, *Rhizophora mucronata*, the stilt roots may be strong and extensively developed, but in others they may be poorly developed (*Rhizophora conjugata*). In some plants, the stilt roots may not at all develop.

(*ii*) Sometimes, a large number of adventitious root buttresses develop from the basal parts of tree trunks. These root buttresses provide sufficient support to the plants.

(*iii*) The soil in coastal region is poorly aerated and it contains very small percentage of oxygen because of water logging. Under such conditions, the roots of halophytes do not get sufficient aeration. In order to compensate this lack of soil aeration, the hydrohalophytes develop special type of negatively geotropic roots, called *pneumatophores* or breathing roots (Fig. 10.1). The pneumatophores usually develop from the underground roots

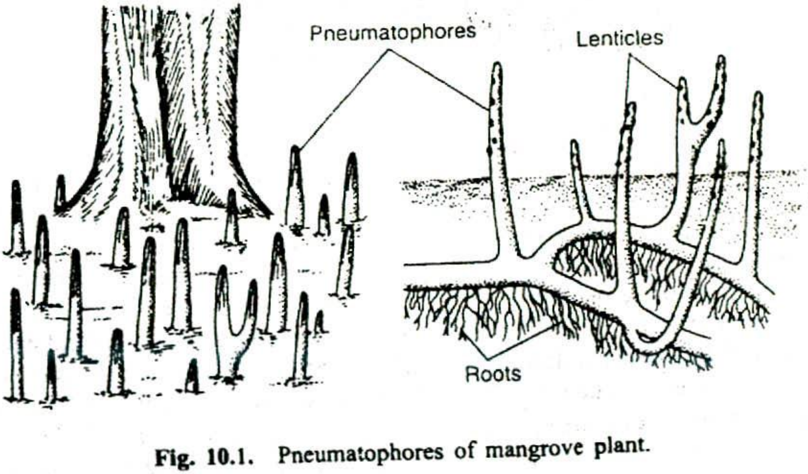

Fig. 10.1. Pneumatophores of mangrove plant.

and project in the air well above the surface of mud and water. They appear as peg-like structures. The tips of these respiratory roots may be pointed. They possess numerous lenticels or pneumathodes on their surface and prominent aerenchyma enclosing large air cavities internally. The gaseous exchange takes place in these roots through the lenticels. The aerenchyma helps in the conduction of air down to the subterranean or submerged roots. In some plants, *e.g.*, *Bruguiera,* the horizontal roots grow above the surface of mud and then again bend downwardly and enter deep into the mud. In this way, they form knee-like structures. The aerial surface bears a number of pores which facilitate the exchange of gases (Fig. 10.2). Pneumatophores do not develop in some species of *Rhizophora.* In those cases, the upper aerial parts of descending stilt roots probably take up the respiratory activity.

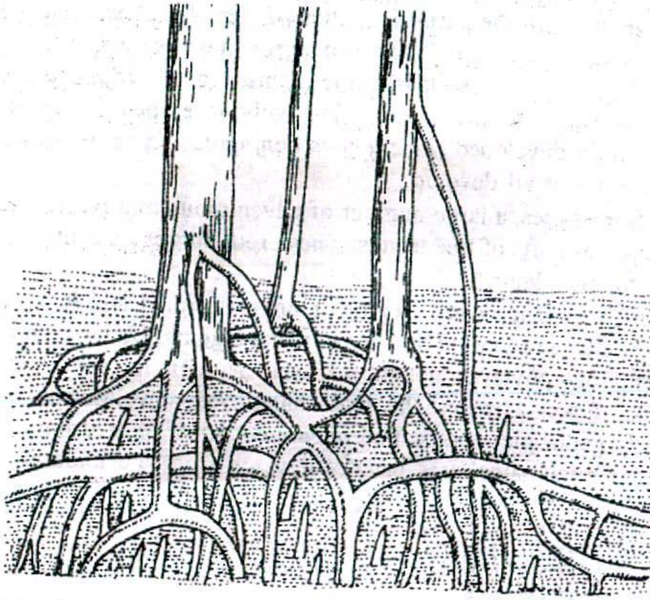

Fig. 10.2. Supporting or stilt roots of mangrove plants developing from the trunk.

(*b*) **Stem.** Stems in several halophytes develop succulence. *Salicornia herbacia* (Fig. 10.3) and *Suaeda maritima* may be quoted as familiar examples for it. According to Arnold (1955) the succulence depends on the ratio of absorbed to free ions in the plant cells rather than absolute amounts of sodium chloride or sulphate present. Succulence is induced only after the accumulation of free ions in an organ increases above a critical level. According to Pokrovskaya (1954, '57) salinity inhibits the cell division and stimulates cell elongation. Such effects cause decrease in the cell number and increase in cell size, so typical of succulents. Repp *et al.* (1959) are of the opinion that succulence is directly correlated with salt tolerance of plants and the degree of their development can serve as an indicator of the ability of plants to survive in highly saline habitats. The temperate halophytes are herbaceous, but the tropical ones are mostly bushy and show dense cymose branching. Submerged marine angiosperms are among the very few species of halophytes that do not become succulent.

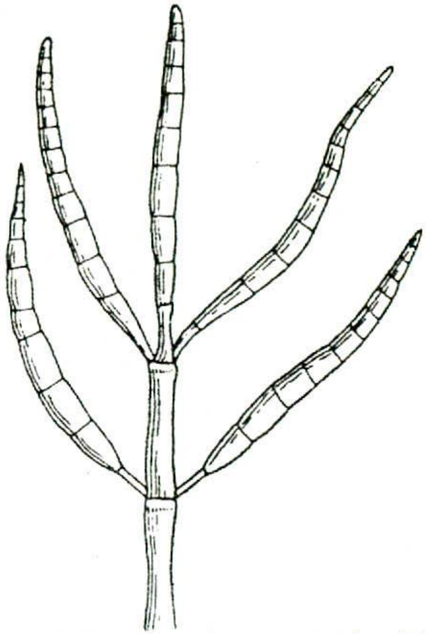

Fig. 10.3. *Salicornia herbacia,* a succulent halophyte.

(*c*) **Leaves.** The leaves in most of the halophytes are thick, entire, succulent, generally small-sized, and are often glassy in appearance. Some species are aphyllous. Stems and leaves of coastal aerohalophytes show additional mode of adaptation to their habitats. Their surfaces are densely covered with trichomes.

Leaves of submerged marine halophytes are thin and have very poorly developed vascular system and frequently green epidermis. They are adapted to absorb water and nutrients from the medium directly.

(*d*) **Fruits, Seeds and their dispersal.** The fruits and seeds are generally light in weight. Fruit walls have a number of air chambers and the fruits, seeds, and seedlings which can float on the water surface for pretty long time are dispersed to distant places by water current. Mangrove vegetations of tropical sea-shores from Australia to East Africa include approximately the same species of plants. Similarly, the mangroves of West Asia show considerable resemblances with those of East Asia and East Africa. It is due, in part, to the fact that medium and temperature remain uniform throughout and partly due to the efficient means of dispersal or migration of plants. A littoral species of *Spinifex* (*S. quarrosus*), a member of Gramineae commonly growing in the sandy saline sea shores in Andhra shows peculiar type of fruit dispersal. In this plant, female inflcrescence is spherical in shape and consists of many spikelets (Fig. 10.4). A number of stiff bractiolar bristles of the inflorescence help in the dancing and somersaulting of the inflorescence. When the seeds mature the globular and hairy inflorescence becomes bodily detached from the creeping plant and trails on the sandy substratum dropping its seeds at places. Finally the inflorescence with rest of fruits becomes buried in the mud.

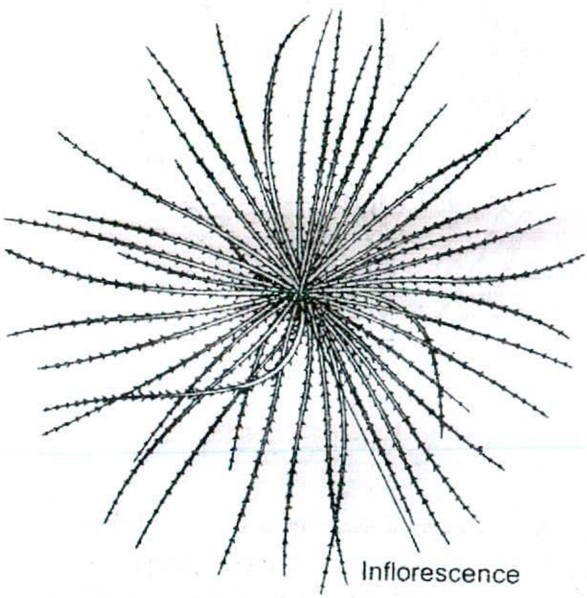

Fig. 10.4. Inflorescence of *Spinifex quarrosus.*

(*e*) **Viviparous mode of seed germination.** Halophytes or mangrove plants growing in the tidal marshes are met with the phenomenon of 'vivipary' which is defined as the germination of seeds while the fruits are still attached to mother plants (Fig. 10.5).

In *Rhizophora* plants, when the embryo reaches advanced stage of development the massive club-shaped hypocotyl and terminal radicle pointing downwardly emerge out of the fruit. When the hypocotyl attains a length of several centimetres (about 50-80 cms), the seedling falls vertically down. Thus, the radicle and a part of hypocotyl become fixed in the mud and the remaining upper part of hypocotyl along with other embryonal parts, such as plumule and cotyledons remains above the surface of mud or water. Within a few hours the radicle develops a tuft of roots and plumule also starts growing rapidly. Sometimes, seedlings fall in deep water and they float on the surface of water vertically with hypocotyl pointing downwards. On reaching shallow areas, the radicle becomes fixed in the soft mud and the plant starts growing rapidly. It is noticed that high degree of salinity in the soil or water checks the germination of seeds. So the viviparous germination is a very significant adaptation in these plants to avoid the retarding effects of salinity on seed germination. Species of *Rhizophora, Aegiceras, Avicennia, Cassula, Ranansatia vivipara* are some of the common examples for vivipary.

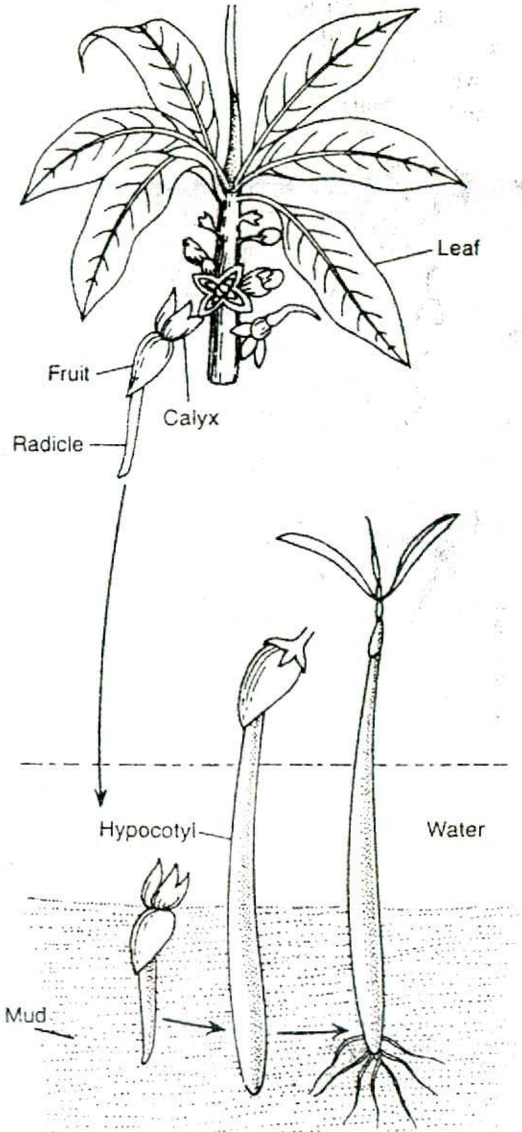

Fig. 10.5. Vivipary in *Rhizophora.*

3. Anatomical Features

The appearance and structures which characterise certain groups of plants sum up to a great extent their ecological and physiological means of adaptation. Halophytes are no exception to this rule because of specific and typical structural characteristics which make them distinguishable from other groups of plants. These are :

1. Large cells and small intercellular spaces,
2. High elasticity of the cell walls,
3. Extensive development of water storing tissues,
4. Smaller relative surface area (surface/volume ratio),
5. Small and fewer stomata, and
6. Low chlorophyll content.

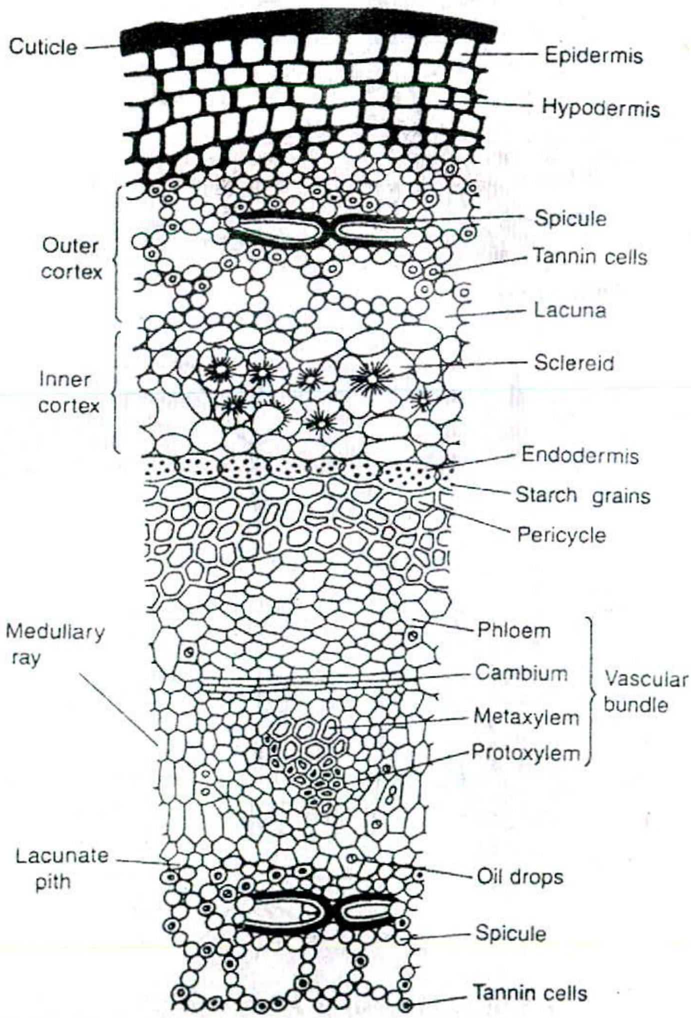

Fig. 10.6. *Rhizophora mucronata.* Transverse section of young stem.

Anatomy of halophytes reveals a number of xerophytic features in them. These are as follows :

(*i*) Presence of thick cuticle on the aerial parts of the plant body. The epidermis of xerosucculents and coastal halophytes is characterised by a cover of waxy layers in addition to thick cuticle (Uphof, 1941) (Fig. 10.6).

(*ii*) Leaves may be dorsiventral or isobilateral. They develop protected stomata which are not deeply sunken. Epidermal cells are thin-walled. The palisade consists of several layers of narrow cells with intercalated tannin and oil cells (Fig. 10.7).

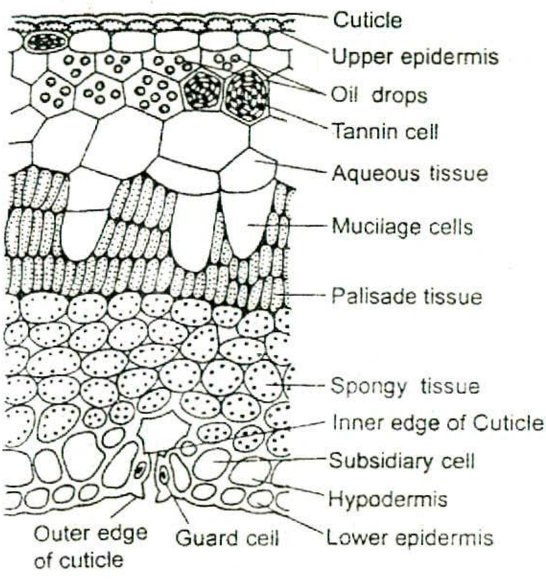

Fig. 10.7. *Rhizophora mucronata.* V.S. of leaf showing detailed structure.

(*iii*) Stems in the succulent plants possess thin-walled water storing parenchyma cells in them. Mucilage cells may be found in abundance. Epidermal cells of various mangrove species contain large quantities of tannins and oil droplets. Cortex is fleshy, several cells thick and in old stems it may become lacunar. Salinity causes extensive lignification of stele (Fig. 10.6).

(*iv*) The leaves and stems of coastal halophytes are abundantly covered with various types of simple and branched trichomes giving the plants a greyish appearance (Fig. 10.8). The trichomes may exert a protective function in plants by :

(*a*) affecting water economy,

(*b*) affecting the temperature of their leaves, and

(*c*) preventing sea water droplets from reaching the live tissues of leaves.

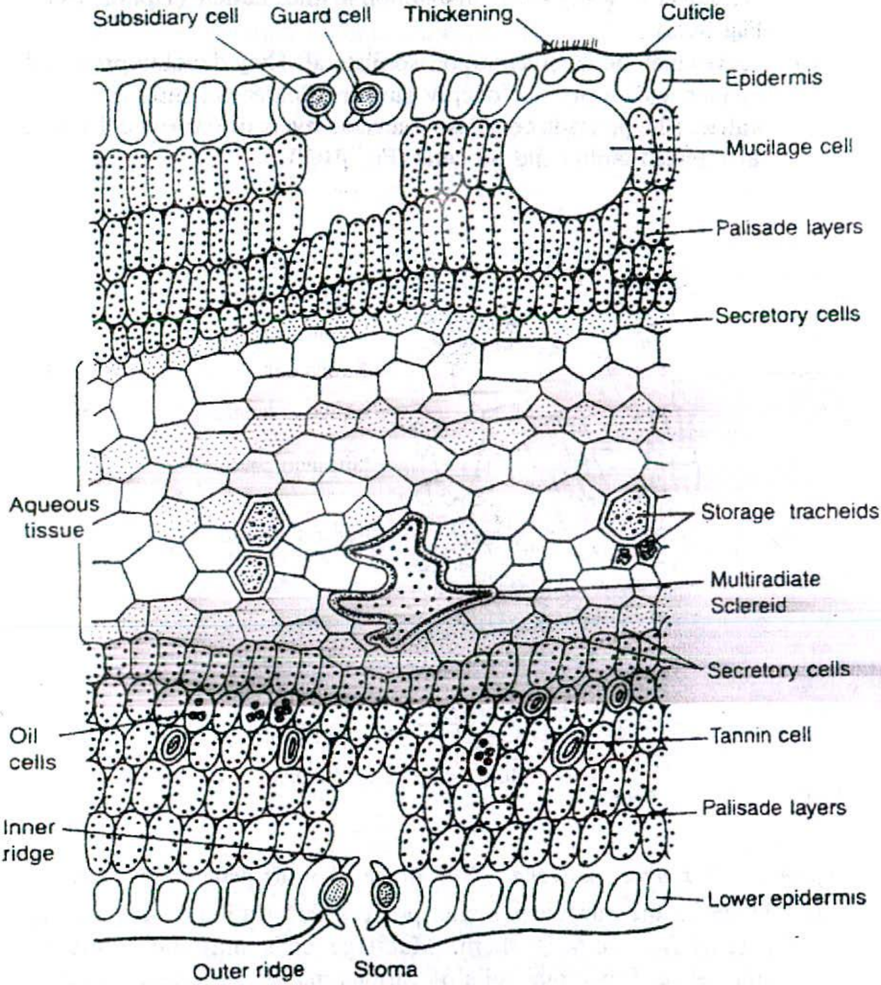

Fig. 10.8. *Sonneratia apetala.* V.S. of leaf showing centrally located aqueous tissue with sclereids and storage tracheids.

(*v*) Leaves of many species of mangrove are dotted with local cork formation "cork warts". Leaves of *Sonneratia* and *Aegiceras* and *Nitraria* (a desert shrub), *Suaeda monoica* contain well developed aqueous tissue (Figs. 10.7, 10.8, 10.9) (Mullan, 1932). Salt secreting glands may be found in some halophytes.

(*vi*) The stilt roots of mangrove plants show normal features with periderm on the surface, aerenchymatous cortex containing sclereids, normal endodermis, secretory pericycle, radially arranged xylem and phloem and extensively developed pith (Fig. 10.10). Pneumatophores develop a number of lenticels on their surface. The cortex is spongy and consists of extensively developed aerenchyma enclosing large air chambers. Highly developed air chambers are continuous with the stomata of leaves and with the cortex and primary phloem of the stems. Pneumatophores show variations in their internal structures. Generally, they show conjoint, collateral vascular bundles with endarch xylem at maturity. Very young pneumatophores, however, show root features, *i.e.*, exarch xylem and radial arrangement of vascular tissues (Fig. 10.10). Generally the negatively geotropic breathing roots show features of stem and not of roots (Fig. 10.11).

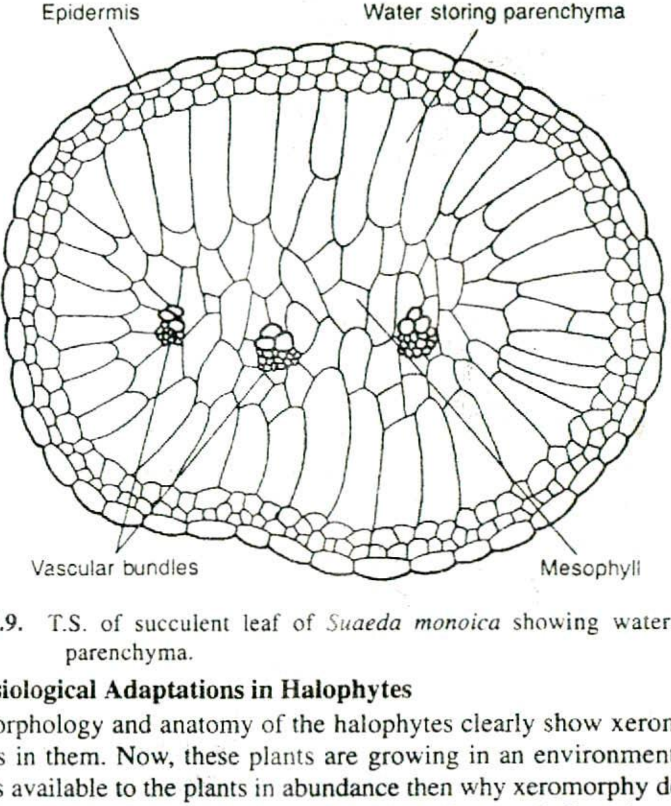

Fig. 10.9. T.S. of succulent leaf of *Suaeda monoica* showing water storing parenchyma.

4. Physiological Adaptations in Halophytes

Morphology and anatomy of the halophytes clearly show xeromorphic features in them. Now, these plants are growing in an environment where water is available to the plants in abundance then why xeromorphy develops in halophytes? Previously physiological drought was believed to be the main cause of developments of xeromorphy in halophytes, but recent physiological experiments on these plants have proved that xeromorphism in these plants is, apparently, an example of purposeless adaptation. Physiological experiments make it clear that the halophytes do not experience difficulties, whatsoever, in absorbing too saline water. This point is concluded taking into consideration the following reasonable facts :

(*i*) they show high rates of transpiration,

(*ii*) they show exudation of sap that contains dissolved salts, and

(*iii*) they develop many shallow absorbing roots.

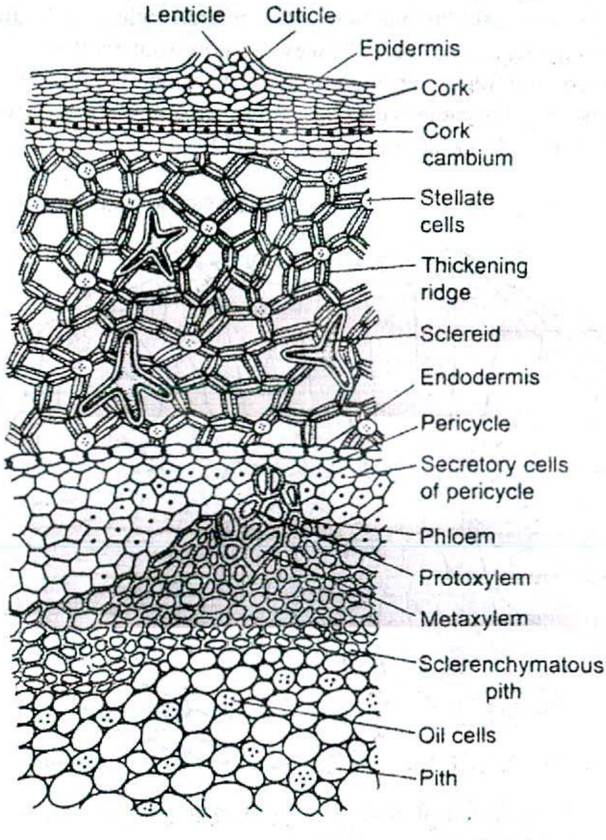

Fig. 10.10. *Rhizophora mucronata.* T.S. of a portion of subterranean stilt root.

Saline conditions are not essentially "dry" for all plant species. Under saline conditions sometimes higher transpiration rates have been observed in halophytes than in neighbouring salt hating plants (Delf, 1911; Braun-Blanquet, 1931).

It should, therefore, be admitted that the halophytes show xeromorphism for enduring high salinity of soil water and also for absorbing water with perfect ease. The significance of succulence is not so clearly understood.

Probably, it is induced by accumulation of salts in cytoplasm. It seems reasonable because of the fact that sodium salts if present in the soil water will definitely stimulate succulence even in non-halophytes and characteristic succulence of some plants may disappear if they are grown on the soil lacking in these common salts. Excessive accumulation of sodium does not harm these plants. Halophytes grow in saline habitats not because they are salt loving but because they tolerate high concentration of salts better than other plants of non-saline habitat. Active accumulation of salts also increases the osmotic concentration of cell sap in these plants and thus makes them able to absorb salty water very easily.

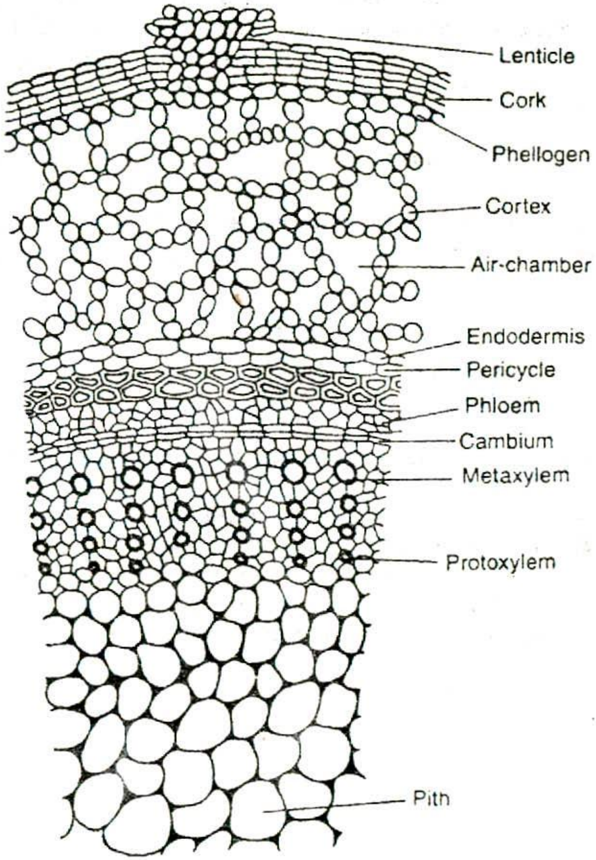

Fig. 10.11. T.S. of a pneumatophore.

Succession of Mangrove Vegetation in Sea Coast

The distribution of a halophytic community appears to be limited by salinity and depth of water table, as well as the competitive ability of the members of next community in the halosere (Reed, 1947). The aggressiveness of plant communities in saline habitat is due to changes in the salinity level.

In coastal region, nature of vegetation is greatly affected by the gradual elevation of sea coast. Succession of mangrove formation in coastal regions may take place very slowly in the following sequence :

(1) In deep water generally true mangroves, *e.g.*, the species of *Avicennia* grow.

(2) When the bottom of the sea is slightly raised up, *Avicennia, Rhizophora, Ceriops, Bruguiera,* etc. form mixed mangroves vegetation in the shallow water.

(3) As the ground is exposed, true mangroves disappear and other halophytes, *e.g.*, species of *Aegiceras, Excoecaria,* etc. gradually invade the land within short period. These halophytic communities are interspersed by salt tolerating succulents and the grasses make the soil fit for the cultivation of some crop plants. Several varieties of paddy, such as *Oryza sativa var, achra,* wild species of *Oryza coarctata* grow very well in these areas.

Successsion of angiospermic halophytes varies also in different habitats in accordance with other ecological conditions besides salinity. Thus, in reality there is no general trend for development of various halophytic plant communities around the world and local variations are encountered in each specific site (Yoav Waisel, 1972).

QUESTIONS

1. What are halophytes? Describe the various characteristic features of halophytes. How do they resemble xerophytes and hydrophytes?
2. Write short notes on :
   Mangrove, Vivipary, Pneumatophore, Physiological adaptation of halophytes.
3. Discuss briefly the classification of halophytes and give an account of distribution of mangrove vegetation in India.
4. What are the various anatomical features which characterise halophytes?
5. How is it that mangrove plants show xerophytic structures in spite of abundance of moisture in the habitat?

11

PRINCIPLES OF PHYTOGEOGRAPHY, CLIMATE, VEGETATION AND BOTANICAL ZONES OF INDIA

PRINCIPLES OF PHYTOGEOGRAPHY

Phytogeography or Plant geography is a science which deals with the distribution of plants on or near the surface of the earth and water. The aspect of ecology which deals with the present and past geographical distribution of organisms on the earth is called **Biogeography**. The study of migration and distribution of animals is known as **Zoogeography** while that of plants is known as Phytogeography. Alexander Von Humboldt is said to be the father of plant geography who wrote the first book on the subject in 1806. On the basis of area of the earth surface occupied by the plants, the various taxa are categorised as under:

1. Wides.
2. Endemics.
3. Discontinuous species.

1. **Wides.** Plants widely distributed over the earth in definite climatic zones and the different continents are referred to as wides. Cosmopolitan is applied for wides but, in fact no plant is cosmopolitan in real sense of the term. *Taraxacum officinale* and *Chaenopodium album* are the common examples of the wides. Plants of tropical regions are called *Pantropical.* The plants of very cold climate may not only be found in the arctic regions but also in alpine zone of mountains in tropical and subtropical regions. These are called *arctic-alpine* plants.

2. **Endemics.** The concept of endemic distribution of plants was putforth by A.P. de Candolle (1813). Engler (1882) suggested two categories of endemic forms; **Paleo-endemics** which are survivors of ancient forms and **indigenous** or **native forms** which are confined to a particular locality.