Ecology

Plants, Environment and Ecological Adaptations

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Contents:

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Environmental factors

Environment may be defined as the surrounding of a living organism. With the realization of a direct interference of man with environment and vice versa, environment also encompasses the social and cultural forces of human society. Environmental factors are external forces either living or non-living that affect the life of the organisms. The non-living environment can further be classified into atmosphere, lithosphere and hydrosphere, whereas biotic environment is called biosphere. Environmental factors are substances (soil, rock, water, air), conditions (light, temperature, humidity, rainfall), forces (wind, gravity), and organisms (plants, animals, microorganisms, human being). Broadly the environmental factors are classified as:

1. Climatic factors: These factors denote the long term average weather conditions of a place for examples temperature, precipitation, wind, humidity, fog, cloud cover and atmosphere gases.
2. Physiographic factors: These include the factors of physical geography of earth such as latitude, longitude, altitude, terrain, angle of slope and aspects.
3. Edaphic factors: These include processes related to the formation of soil and physical, chemical and biological characteristics of soil.
4. Biotic factors: These factors denote all kinds of influences caused by living organisms including man

Environmental factors do not act individually, but many factors interact to influence the existence and success of an organism, known as interaction of environmental factors. The intensity, importance and time scale of factors, however, vary with organisms and ecosystem types

Climatic Factors

Climate is a product of weather, which is day-to-day condition of light, temperature, precipitation, humidity, and wind and air pressure. Climatic factors are mainly concerned with aerial environment of organisms. Following are important climatic factors.

Solar radiation

The sun makes all life on earth possible. It provides habitable temperature, otherwise the average temperature of the planet would approach -33^{O} C when all water would be frozen. Sun's energy is utilized by photosynthetic organisms to convert in food molecules required by almost all forms of life. The amount of solar radiation that reaches a point just outside the earth's atmosphere (at a height of 83 km) measured perpendicular to the sun's rays is known as solar constant. Solar constant is estimated as 1.98 langley min^{-1} or 1.94 cal cm^{-2} min^{-1}.

Earth reflects back a percentage of the solar radiation, called albedo. Global albedo varies from 50 to 60% at Polar Regions and to 20 to 30% in equatorial region. Water surface has a low albedo, whereas for snow and ice, albedo may be as high as 45 to 90%. The atmosphere reduces solar radiation at extra terrestrial level of about 1.94 cal cm^{-2} min^{-1} to about 1.3 cal cm^{-2} min^{-1} at sea level on a clear summer day.

The earth surface receives approximately 1 langley min^{-1} in the form of short wave radiation. If solar radiation reaching the atmosphere is considered 100 per cent, 25% is reflected by atmosphere (clouds) and 5% by earth's surface back to space (Figure 1). Another 25% is absorbed by dust, water vapour and carbon dioxide in the atmosphere. Thus reflection and absorption remove 55% of the solar radiation reaching the earth surface. Earth absorbs remaining short wave radiation, which is radiated back as long wave radiation and is absorbed by the atmosphere. Again there is escape of 12% energy to outer space and the remaining 33% is absorbed by water vapour and carbon dioxide in the atmosphere. This heat, radiated back to earth, maintains warmer surface temperatures. Nearly all the ultraviolet radiation is absorbed by the upper atmosphere. This scatter of shorter wavelength gives bluish colour to the sky.

The energy of solar radiation can be measured by **pyranometers**, which can measure direct and diffuse sunlight. Plant leaves absorb relatively high radiation at wavelengths shorter than 700 nm i.e. of visible and ultraviolet wavelengths. Chlorophylls, carotenoids and xanthophylls absorb highly in visible range. Chlorophylls reflect green light and absorb much of violet, blue and red, while carotene and xanthophylls reflect yellow to orange and absorb heavily in the blue to green range.

Sun's rays hit the earth vertically near the equator making energy more concentrated and producing higher temperatures. In contrast sunrays are inclined near poles and pass through deeper envelope of air resulting in high level of scattering and reflection of sun's energy leading to lowering of temperature near poles. The inclination of earth's axis and the distance of the earth cause seasonal variations in solar energy reaching the earth surface. Differences in temperature caused by variations in the amount of solar energy reaching the earth at surface drive the circulation of the air.

The radiation travels in form of energy packets called photons. The energy contained in one photon is inversely proportional to the associated wavelength, the shorter the wavelength, more the energy content. Gamma rays, X-rays, UV-C (<280nm) are highly energetic and harmful, but do not reach ground level as absorbed by atmospheric gases. The ultraviolet radiation is of high intensity short wavelength of 100 to 400 nm. UV radiation is of three types i.e. UV-A (320 – 400nm), UV-B (280-320nm) and UV-C (100-280nm). Visible radiation contains less specific energy, but has the highest total energy content due to large number of photons. Maximum energy is radiated in the visible band around 500 nm. As the path length increases with latitude, the amount of radiation decreases. Equator receives high intensity than poles, but longer hours of sunlight compensate loss of intensity at high latitudes.

Photosynthetically active radiation (PAR): Solar radiation reaching vegetation has two components (1) irradiance of direct sunlight, and (2) diffuse irradiance from clouds and clear sky. The wavelengths absorbed by photosynthetic pigments are between 400 to 700 nm. This band of light is called photosynthetically active radiation (PAR). About one third of direct solar beam is photosynthetically active radiation and two third in diffuse radiation. Typical instantaneous values of PAR at vegetation surfaces under clear sky conditions vary from 500-1000 W m^{-2} and from 50-200 W m^{-2} under cloudy conditions. PAR is also referred as photosynthetic photon flux density (PPFD), which is photon flux per unit area in the same wave band and expressed as μ mol m^{-2} s^{-1}. The intensity of PPFD would be about 2000 μ mol m^{-2} s^{-1} near mid day on a clear sky.

Atmospheric Constituents

The envelope of air surrounding the earth is atmosphere, which helps in maintaining temperature on earth surface tolerable for living organisms filters out high energetic harmful radiations of sun and provides life support gases to the organisms. Atmosphere is composed of a mixture of gases. Nitrogen and oxygen contribute 99% of the atmospheric gases. The rest 1% comprises many inert and other chemically active gases. In addition water vapours, oxides of nitrogen, sulphur dioxide and chlorofluorocarbons also add to the composition of the atmosphere. Aerosols, which are very small sized suspended particles of dust are also part of the atmosphere. Aerosols absorb and scatter radiation and thus from a very important component of the atmosphere. O3 absorbs harmful UV-B radiation of sun thus protecting the life on earth. Hydroxyl ions (OH) help in removing polluting gases from the atmosphere, by oxidizing them in liquid or aerosol forms.

Water vapour content is variable in atmosphere depending on location, time of day and season. Water vapours act as an independent gas, which has weight and exerts pressure. The amount of pressure water vapours exert independent of dry air is vapour pressure. The pressure that water vapour exerts when air is saturated is saturation vapour pressure, a characteristic, which is a function of temperature. At higher temperature of earth, moisture content may be as high as 4 to 5% leading to reduction in proportion of major gases N_2 and O_2. Water vapours are the carrier of heat energy from the oceans to higher altitudes. The difference between actual vapour pressure and saturation vapour pressure at any given temperature represents the vapour pressure deficit. The rate of movement of moisture is proportional to vapour pressure differences.

The amount of water vapour a given volume or weight of air holds is expressed in terms of absolute humidity (g m^{-3}). Moisture content, expressed as a ratio of the actual moisture content and that required to saturate the air at the same temperature is called relative humidity (RH). For example if the actual amount of water vapour in the air is only 40 per cent of the amount it could hold if saturated, the relative humidity is 40 per cent. The atmosphere receives water vapours through the process of evaporation from oceans and other water bodies and through transpiration from vegetation. Warm moist air rises upwards, but due to decrease in pressure upward, the ascending moist air cools below the saturation point and results in condensation on suspended dust or other hygroscopic particles to form clouds. With more and more condensation, cloud droplets grow bigger and heavier and ultimately result in rainfall.

O_2 is a good absorber of UV radiation upto 180 nm. The wavelengths between 200 to 280 nm are completely absorbed by O_3 while 280-315 nm (UV-B) are partially absorbed based on O_3 density in the stratosphere. UV-A (315-400 nm) and visible radiations reach the ground level without much attenuation. The gases such as CO_2, CH_4, N_2O, H_2O and O_3 naturally present in the atmosphere have high absorption at long wavelengths so these allow the solar radiation of shorter wavelengths to penetrate the atmosphere, but disallow the radiation of longer wavelength to escape from the atmosphere. This enables the earth to maintain a global mean temperature of 15 ^{O}C, this is referred as green house effect causing natural atmospheric warming. The atmospheric gases causing this effect are called green house gases or radiative gases.

Water

Water is one of the most important environmental factors regulating the existence of life on earth. Water shortage has been the main concern of human race at present. Oceans cover 71% of the earth surface with a mean depth of 3.8 km. Oceans hold 97% of the all earth's waters. Fresh water resources represent only 3 per cent of earth's water supply. Out of the total fresh water on earth, 75 per cent is locked up in glaciers and ice sheets. This constitutes more than 2 per cent of fresh water and leaves less than 1 per cent of available fresh water in liquid form. Ground water accounts for 25 per cent of fresh water. Renewable and cyclic ground water is roughly estimated at 7 X 106 km^3. Some of this ground water is inherited in aquifers of desert regions for more than thousands of years. A portion of the ground water lying below 1000 m is known as fossil water. This is often saline and does not participate in the hydrological cycle. Lakes contain 0.3 per cent and on average rivers and streams contain only 0.005 per cent. Soil moisture accounts for approximately 0.3 per cent. Another small portion is tied up in living organisms. The atmosphere contains 0.035 per cent fresh water in form of water vapours and clouds.

Fresh water resources are either lentic having standing water bodies such as lakes and ponds or lotic, running water bodies such as rivers and streams. Water is constantly being recycled in all its states between atmosphere, land and oceans. This cycling is called **hydrological cycle** or **water cycle** (Figure 2). The major processes drawing the hydrological cycle are evaporation, evapotranpiration, precipitation and runoff. The water cycle starts with evaporation of water from oceans, lakes, rivers and through plant leaves. This loss of water from surface of land and plant leaves then forms water vapours in the atmosphere where it condenses at cool temperature and form clouds. The atmospheric water falls in form of precipitation or rain on land and oceans and distributed to fresh water bodies. Some infiltrates to the permanent water table and some remains in the top soil layer to be used by plants. Extra water moves in surface channels as surface runoff into rivers, streams, lakes and finally to oceans. Some of the water reaches the ground directly, and some is intercepted by vegetation, litter on the ground, and structures. A forest in full leafing condition may intercept a significant portion of a light rain. Water exceeding the storage capacity of canopy either drips off the leaves as through fall or runs down the stem and trunk as stemflow. In urban areas, a larger proportion of precipitation on roofs and streets runs down to drains and to the rivers without being intercepted by soil. The precipitation reaches the ground through soil by infiltration, which is governed by the factors such as soil types, vegetation, terrain and amount of rain fall. Water moves through the soil by the action of capillary attraction and gravity. Vegetation tends to roughen the soil surface and allows the water to move into the soil, whereas in urban areas because of low infiltration, surface run off may reach 85 per cent of total precipitation. Water losses from soil also take place through plants by the process of transpiration. The loss continues till moisture is available in the soil, roots are capable of removing water and amount of energy is available to supply the necessary latent heat of evaporation. The total flux of water evaporating from surface of the ground and vegetation is called evapotranspiration. If the total water on the earth is considered in terms of 100 units, then the average 84 units are lost from the oceans by evaporation, while 77 units are returned through precipitation to the oceans. Land areas lose 16 units by evaporation and gain 23 units by precipitation. Run off from land to oceans makes up 7 units, which balances the evaporative deficit of the ocean. The remaining 7 units circulate as atmospheric moisture. About 0.005 per cent water is all the time moving. The mean annual rainfall on a global basis is 85.7 cm out of which land receives 23% and oceans, 77%. Through evaporation and transpiration oceans and plants supply 84 and 16% water vapours, respectively.

Wind

Wind is an important environmental factor as it governs transpirational water loss from vegetation, dispersal and dissemination of seeds and pollination in plants. Wind velocity varies at different geographical situation and along vegetation types. Wind plays more important role at sea shores and at high altitude mountains. Air heated at the equatorial regions rises until it reaches the stratosphere, where it is blocked from any upward movement. These air masses are forced to move north and south towards the poles. Above poles, they cool become heavier, and sink. The pattern of rising and descending air forms circulation cells near equator, mid latitudes and polar region called **Hadley cells**, **Ferrel cells** and **polar cells**, respectively. The interaction of wind and heating produces high pressure cells known as subtropical highs in the Atlantic and Pacific oceans. Winds and cooling interaction produce low pressure cells such as the Aleutian and Icelandic lows. Seasonal winds are also important because dry winds blow from continental interiors to the oceans during early summer and winds heavy with moisture blow from oceans to the content in rainy or winter, bringing heavy rains. Major air circulations are responsible for the changing cloud pattern on the earth.

Physiographic Factors

Earth surface is not even. Latitude, altitude, inclination of earth's axis at an angle, revolution of earth, location of region within the continental land masses, nearby bodies of water and geographical features such as mountains influence the environment indirectly through their effects on weather and climate. Mountains influence regional climate in two ways; by modifying the pattern of precipitation and by creating climatic differences with altitude. When an air mass is intercepted by a mountain range, it ascends, cools, reaches to its condensation point and falls in the form of rains or snow on the windward side. The dry air then descends on the leeward side, warms and picks up moisture from the land. Such pattern results in more moisture in windward side and a drier condition in the rain shadow leeward side. Mountain areas show wide variations in climate along an altitudinal gradient similar to that experienced by going to higher latitudes. Temperature drops to about 1.5 to 3 ^{O}C for every 300 m rise in elevation.

Heat, moisture, air movement and light vary from hill to mountains slope, valleys, and surface of the ground and beneath vegetation, thus creating a range of climate. South facing slopes in the northern hemisphere receive more solar energy as compared to north facing slopes. This has marked effect on moisture and heat budget of the two as aspects. The evaporation rate is often doubled, the average temperature higher and the soil moisture is lower at south facing than north facing slopes. Thus warm and xeric conditions prevail on south facing slopes as compared to cool and moist north. Facing slopes. Steepness of the slope is also important on top of the south facing side because of high speed air movement and poor soil drainage and at the valleys in north facing slopes due to water logging. Vegetation occupying two different sides of slope is also different, which further influence mineral recycling, physico-chemical characteristics of soil and nature of ground cover.

Edaphic Factors

Soil is the weathered outer layer of earth's crust, which ranges from a thin film to thick layers composed of weathered rock materials and organic matter interspersed with pores filled with air and water, and which supports plant life. Soil not only provides water and mineral nutrients to the plant for manufacture of various organic compounds, but minerals to the soil through the process of decomposition and mineralization. Soil is home to many types of animals.

Soil formation

The soil formation is a complex process resulting from solid rock, or from mineral material deposited by a glacier, wind or water. The process of soil formation initiated with weathering process is called **pedogenesis**. Weathering may be mechanical, chemical or biological. Mechanical weathering results from cracking of big rocks into little ones by the wedging action of water freezing in a crack, expansion of tree trunk, root penetration and forces created by the beating of rain splashes. Chemical weathering is caused due to reaction of mineral matter with water through processes of oxidation, reduction, hydrolysis and carbonation. Biological weathering is caused by chemical substances produced by plants, which break down to weather rocks. The lower plants produce CO_2 in rock crevices and surfaces, which dissolve in water to produce carbonic acid causing weathering of rocks.

Any vertical cut through a body of soil is called **soil profile**. The apparent layers of soil are called horizons. Each horizon has characteristic set of features related to colour, thickness, structure, consistency, porosity, chemistry and composition.

In general soils have five major horizons: O, an organic layer, and A, E, B and C, the mineral layers (Figure 3). Below these layers, non soil horizon R lies. The O horizon is composed of fresh or partially decomposed organic matter not mixed into mineral soil. The horizon O is further subdivided into an O_i, the litter layer and O_a, the humus layer. The A (earlier called A_1) horizon is the upper layer of mineral soil with high content of organic matter. O and A horizons constitute the zone of maximum biological activity. The E (earlier called A_2) horizon is the zone of maximum leaching (eluviation denoting E). The downward movement of suspended and dissolved material through leaching alters soil and structure. The B horizon is the zone of illuviation, the collection of leached material like silicates, clay, iron, aluminum, etc from E horizon. It has a characteristic physical structure with blocky, columnar or prismatic shapes. C horizon refers to the layer where active weathering occurs from the unweathered material in horizon R below. Horizon R is consolidated bedrock.

Properties of soils: Soils vary in their physical and chemical properties.

Physical properties: These include colour, texture, structure, depth and moisture. Brownish black and dark brown colours in the A horizon indicate high organic matter. Very pale brown to reddish colours of B horizon are characteristics of well drained soil, whereas dark brown to blackish colours of B horizon indicate poor drainage. Red soils derive their colour from presence of iron oxides. The bright colours indicate good drainage and aeration. Red and yellow colours increase from temperate to the equator. Greyish colour denotes permanently saturated soils in which iron is in ferrous form. The colours of soils are determined by the use of standardized colour charts known as **Munsell colour charts**.

Texture: Soil texture is determined by the relative proportion of mineral particles classified as gravel, sand, silt and clay. Gravel consists of particles larger than 2.0 mm size. Sand ranges from 0.5 to 2.0 mm and upon touch feels gritty. Silt consists of particles from 0.002 to 0.5 mm and is not visible by naked eye and feels like flour. Clay particles are less than 0.002 mm and decide the plasticity of the soil and exchange of ions between soil particles and soil solution. Based on percentages of sand, silt and clay, soils are classified into different textural classes. Texture decides pore space and therefore the movement of water and air and penetration of roots. Coarse textured soils possess large pore spaces that favour rapid water filtration and rapid drainage. Fine textured soils have high proportion of clay and are poorly aerated.

Soil particles are held together in clusters or shapes of various sizes called **aggregates** or **peds**. The arrangement of these aggregates is called **soil structure**. Soil aggregates are classified as granular, crumb like, plantlike, blocky, prismatic and columnar.

Depth: The layers of soil vary in depth depending on slope, weathering parent material and vegetation. Soils are several meters deep under native grasslands but relatively shallow under forest.

Moisture: Water in soil can be **gravitational water, capillary water and hygroscopic water**. The maximum amount of water the soil will hold following the drainage of gravitational water is called **field capacity**. It consists of capillary water plus hygroscopic water. The metric tension of soil at field capacity varies between 0.1 and 0.3 bar. Capillary water is retained by capillary action against the pull of gravity in smaller pores of soil and is the main source of water to the plants. Hygroscopic water is adsorbed on the surface of soil particles. **Permanent wilting percentage** is the amount of water in a soil when plants growing in it are irreversibly wilted. At a soil metric tension value of about 15 bars, majority of plant except xerophytes wilt permanently. The amount of organic matter also increases water retention capacity of soil.

Chemical properties: Chemical elements in the soil are dissolved in soil solution, part of organic matter and are adsorbed on the soil particles. Positively charged minerals called cations are stored on the surface of the particles, whereas anions are dissolved in soil water. Plant roots absorb cations by replacing them with hydrogen ions. The total number of negatively charged exchange sites on clay and humus particles that attract positive charged cations is called **cation exchange capacity (CEC)**. The negative charges enable the soil to prevent the leaching of cations. Exchange sites are occupied by calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na^{+}) and hydrogen (H^{+}). The percentage of sites occupied by ions other than hydrogen is called the per cent base saturation. Acidity of soil is one of the most important chemical characteristics. Typical soil ranges from a pH of 3 (strongly acidic) to pH of 9 (strongly alkaline).

Biological properties: A variety of organisms are part of soil. Dominant organisms are bacteria, fungi, protozoans and nematodes. Spaces within the surface litter, cavities in soil aggregates, pore spaces within individual soil particles, root channels are habitat for soil organisms, which obtain food from roots of living plants and organic matter within the pore spaces. The most abundant soil animals are mites. Among the larger fauna are the earthworms. Feeding on the surface litter are millipedes, causing mechanical breakdown of litter, making it more vulnerable to fungal decomposition. Millipedes live on fungi in the litter. Snails and slugs also accompany millipedes and help in hydrolyzing cellulose and even highly indigestible lignins. Termites and some dipteran are larger inhabitants causing breakdown of cellulose of wood. Termites dominate the tropical soil fauna.

Soil organic matter, which originates from biological activities during decomposition strongly influences the development of O and A horizons. The fraction of organic matter that remains after decomposition is called humus, which is dark colour, chemically complex organic material with characteristic constituents like fulvic acid and humic acid. Two types of humus formation occur due to interaction of physical, chemical and biological mechanisms; Mor: It has a well defined, unincorporated compact organic deposit resting on mineral soil. There is a sharp distinction between horizons O and A. The main decomposing agents are fungi, which depress soil animal activity and produce acid. Mull: It possesses only a thin layer of litter on surface and mineral soil has high organic matter. Animal activity is very high. There is no sharp break between the O and A horizons. Bacteria are the main decomposers in this soil.

Soil development

Soil continues to develop over time due to climate, vegetation and other factors. Major processes in soil development are podsolization, laterization, calcification, gleyization and salinization.

Podsolization: denotes the ash colour of the soil due to depletion of bases from surface layers to the B horizon. The organic horizon is a mor with a layer of fermented litter on top of a layer of humus unmixed with mineral soil. Such soils are highly acidic and develop under coniferous forests in cool humid regions.

Laterization: is common in humid sub tropical and tropical forested regions, where rainfall is heavy and temperature is high. Weathering is entirely chemical brought by water and its dissolved substances. Bases, silica, Al, hydrated aluminosilicates and iron oxides become soluble and carried down ward. The weathered end product is composed of silicate, hydrous oxides, clays deficient in bases and low in plant nutrients. The large amount of residual Fe and Al hydroxides gives bright reddish colour in upper part of E horizon, which may be especially deep.

Calcification: The sub humid to arid and temperate to tropical regions supporting grassland vegetation show calcification. Vegetative material above ground and part of root system turned back to soil as organic matter every year and thus developing soil is high in organic matter. Rainfall is generally not sufficient to remove calcium and magnesium carbonates and grasses help in maintaing of soil a high calcium content of soil by redepositing during decomposition. In this process of soil development A horizon is distinct and CaCO3 and leaches to the B horizon where calcium nodules are formed, which are called kanker.

Gleyization: Under poor drainage condition of cold wet situation and where water table is high upto B and C horizons, compact structureless horizons develop and this process is called gleyization. Organic matter is high due to reduced rate of humification and soil has dull gray to bluish colour. Iron stays in reduced ferrous compound most of the time.

Salinization: In arid and semi arid regions with sparse vegetation and scant precipitation, slightly weathered and slightly leached soils are formed. The horizons are very thin and soils contain very high amounts of soluble salts. Due to high rate of evaporation a more or less cemented horizon of Na, Ca and Mg salts is formed below surface. This horizon is called caliche. Soils are low is humus and high in base content.

Adaptations to Environmental Factors

Any environmental factor that inhibits the growth of plant either through its deficiency or excess is said to be a limiting factor. For example cold temperature restricts plant growth at higher elevations and water availability in desert. Limiting factors for terrestrial plants are light, moisture and temperature. Liebig's Law of minimum states that growth of plants is dependent on the amount of nutrient present in minimum quantity. Shelford's Law of tolerance suggests an ecological minimum and an ecological maximum and the range between these two conditions represents the tolerance range of plants. The plants with narrow range of tolerance to temperature are called stenothermal and those with wide range of tolerance are called eurythermal.

A plant does not do equally well throughout its whole range of distribution. There is a range of environmental condition, where it does better and this is referred as the range of the optimum. When some feature of environment changes, the plant responds accordingly. These changes keep certain important aspects of the plant's internal environment constant despite of changing external environment. This tendency is known as homeostasis. When the environmental factor changes beyond a certain level, plants try to adapt. Adaptation is any morphological, anatomical, physiological or behavioural feature, which favour results from some environmental pressure to increase the ability of an organism under changing environment and favour the success of an organism in a given environmental condition. The populations showing non-heritable differences in morphology due to varied natural environment are called **ecophenes or ecads**. The differential success or fitness of populations comes through process of natural selection. A given population shows different levels of tolerance to a given limiting factor over its geographic distribution. Such locally adapted populations are called ecotypes, which may have developed due to genetic changes resulting in different responses to varying environment. The genetic responses of individuals under a particular set of conditions are expressed in phenotypes. The phenotypic responses may be morphological (physical characteristics), physiological (functional characteristics) or phenological (timing of growth, flowering and other life history changes). The ranges of adaptiveness influence distribution of plants and their population. The plants possessing a wide range of tolerance to many environmental factors will be most widely distributed.

Adaptations to light variations

Light plays many important ecological roles but the two most important aspects of light are relative light requirements and photoperiodism. Ecologically plants are classified on the basis of their relative light requirement for overall vegetative development as heliphytes and sciophytes. Heliophytes require full sunlight for best growth. Sciophytes grow best at lower light intensities. Some heliophytes can also grow fairly well under shade and are called facultative sciophytes. On the other hand some sciophytes can also grow well under full sunlight and are called **facultative heliophytes.**

Heliophytes grow best in open sites and establish rapidly on disturbed sites, tolerate extremes of dryness and wetness and have a high rate of photosynthesis as well as respiration. Shade tolerant plants have lower rate of photosynthesis and more importantly a lower rate of respiration. Sciophytes carry on photosynthesis at low light intensities. Leaves of heliophytes are smaller, thicker and more deeply lobed than sciophytes, with well developed support and conduction systems. Shade leaves are thinner, weakly lobed, have large surface area per unit weight, fewer stomata and less support and conduction tissues. These adaptations increase efficiency of light utilization, increase area for light interception and reduce reflection. Sciophytes have a lower dark respiration and therefore a lower light compensation point allowing maintaining a positive carbon balance even at very low gross photosynthesis rate. When shade plants are exposed to full light, they lose an excessive amount of moisture and experience light damage to the chloroplasts. Many forest herbaceous plants are shade tolerant. Heliophytes if forced to grow in the shade will respond by growing rapidly in height in an attempt to emerge from the shade. The leaves will be thinner and more widely spaced, making them susceptible to drought and fungal infections. To avoid bright light, plants develop some characteristics such as vertical orientation of leaf blades, thicker stem, well developed conducting elements and mechanical tissues, thick palisade layer, longer root, shorter internodes, more branching, higher root/shoot ratio, lower chlorophyll content, higher respiration rate, higher osmotic pressure due to high concentration of salts and sugars, more resistance to temperature, drought and pest injury. Most shade tolerant trees have low growth rates, but their growth was not reduced as much by low light.

C4 plants have higher light saturation levels than C3 species. PAR is frequently limiting to desert plants with CAM photosynthesis. Cacti tend to grow oriented in a way that maximizes light inception during the season when other environmental factors are optimal for photosynthesis. In marine environment, the pattern of distribution of different algae is explained by different absorptive spectra of the photosynthetic pigments. Red algae found in deepest water have phycobilin pigments, which can absorb green wavelengths common at those depths. Green algae with chlorophyll a and b are inhabitants of shallow water, whereas brown algae with chlorophyll a and c and special carotenoid pigment fucoxanthin are common at intermediate depths.

Photoperiodism: Light has both direct and indirect effects. It affects metabolism directly through photosynthesis, growth and development and indirectly as a consequence of the immediate metabolic responses and its control of morphogenesis. Spectral distribution of radiation has impact on germination, stem extension rates and apical dominance. Light responses are mediated by three main receptor systems. Chlorophyll for photosynthesis, phytochrome absorbing in two interchangeable form at 660 and 730 nm for many photomorphogenetic responses and flavins absorbing at 450 nm for tropisms and high energy photomorphogenesis. Temporal variations in irradiance and its relative duration day/night vary with latitude. This is the basis of photoperiodism. All temperate zone plants exhibit photoperiodic responses for flower initiation, seed germination, bud break, stem elongation, leaf fall and other processes. This is of less value in equatorial region as day length shows little seasonal variation, compared to that in temperate region. The photoperiodic response enables the plant to time the vegetative and floral growth to fit seasonal changes in the environment.

The activities of plants are geared to the changing seasonal rhythms of day and night. The signal for these responses is critical day length. It varies somewhere between 10 and 14 hours. On the basis of photoperiod, plants may be classified as (I) short day plants, which develop and reproduce normally only when photoperiod is less than a critical maximum (12-14 hrs), such as Cannabis sativa, Andropogon virginicus and Datura stramonimum,(II) Long day plants are those whose growth and reproduction are stimulated by day lengths larger than the critical day length such as Brassica rapa and Sorghum vulgar. Some plants are indifferent to photoperiod and are called (III) day neutral plants, such as Cucumis sativus, Poa annua and Nicotiana tabacum, which in different to the length of photoperiod.

Adaptations to temperature variations

Temperature affects metabolic processes of plants by influencing the kinetics of biochemical reactions and the effectiveness of enzymes. The thermal environment of plants varies a lot from one part to another. Roots are generally buffered from temperature extremes by the soil, while the above ground structures are exposed to a wide range of temperatures. Temperature of leaves, twigs and buds exposed to sunny side is higher than the shaded side. Plants maintain heat balance by reradiation, convection and transpiration. During each part of the life cycle, plants may have a different set of optimum temperature. The temperature required to stimulate germination may be lower than that favouring flower development. Optimal temperatures vary among species, ecotypes within species, and among individuals in a population. Heat stress: In response to heat stress, net photosynthesis drops and respiration becomes dominant. In heat tolerant species, rapid rise in temperature leads to shut down of normal protein synthesis coupled with initiation of a set of heat shock proteins that help in short term survival. If the heat persists, it disrupts the protein structure of the plant. Many species of cacti acclimate to high temperatures because they have high levels of bound water and high cytoplasmic viscosity. Many plants have very small leaves or no leaves at all and carry on photosynthesis through stems. Such palnts are called phylloclades for example Ophuntia and Muehlenbeckia. Short term tolerance to heat stress involves a response by some behavioral means. Under heat stress plants hang their leaves parallel rather than horizontal to the sun's rays. Heat tolerance varies with developmental stages as germinating and young plants and growing organs are more sensitive to heat stress than adult organs. C4 plants have ability to carry on positive photosynthesis at higher temperature than C3 plants and therefore usually tolerate warmer temperatures compared to C3 plants. This disadvantage of C3 plants is mainly ascribed to high rate of photorespiration at warmer temperature. The C3 plants may have higher amount of CO2 absorbed per unit of light, but will lose that advantage due to greater photorespiration at higher temperature. CAM photosynthesis is also regulated by temperature because night time CO2 uptake is dependent upon low temperature. In desert plants, stomatal resistance increases several fold when leaf temperature increases.

Cold stress: Plants of cold climate develop tolerance to cold temperature and even when temperature drops below minimum for growth, photosynthesis and respiration may continue slowly. Plants of tropical and subtropical regions may suffer lethal damage at temperatures just above freezing i.e. close to 0 ^{0}C. Damage due to chilling and frost depends upon the magnitude and duration of drop in temperature. Sensitive plants experience damage to cell membrane and lose electrolytes rapidly. If freezing occurs slowly, ice crystals are formed outside the cells drawing water from the cells thus causing dehydration. In case of temperature falling rapidly, ice crystals are formed within cells thus damaging cell structure. When the tissues thaw, the cellular contents spill out. Chilling and frost damage is avoided by increasing the sugars and alcohols, which help in lowering the freezing points of cytoplasm. This can allow super cooling of cell sap without injury for short period.

Winter dormancy is common in plants of cold climates to tolerate frost. Plants harden themselves by producing organic compounds, such as sugars, amino acids and nontoxic substances, which act as antifreeze. This acquired tolerance is retained until growth starts with favorable conditions. Among the plant parts, roots, bulbs and rhizomes are most sensitive to freezing stress. Terminal buds of trees are less resistant to cold than lateral buds, which in turn are more sensitive than basal buds on twigs. Woody stems are more resistant than leaves. Insulation is another way to resist chilling and frost damage. The cushion type and rosette plants of arctic and alpine and temperate regions may keep the temperature 10-20°C higher than the surrounding air.

Thermoperiodism: Many plants require a day night temperature difference for optimal growth. A positive response to a thermoperiod, which is a diurnal difference, is termed thermoperiodism. A thermoperiod requirement is adaptive in the pines and firs because of great diurnal temperature fluctuations in their areas of abundance. Some species show positive response to temperature depression during the dark period. Dormancy: The dormancy of apical buds of many woody species of temperate climate is initiated by short days interacting with cold temperature. The environmental stimulus that enables the plant to perceive the passage of winter is cold temperature. Most plants growing at higher latitudes possess seeds that require cold temperatures for germination. Such seeds are dormant prior to exposure to cold temperature.

Vernalization: The flowering of cereal plants is influenced by exposure to cold temperature during the time of germination. This cold exposure response is called vernalization.

Sumorization: Heat cracking is essential for the rupturing of the seed coat of some fire adapted plants. Heat pre-treatment also promotes germination of desert annuals. This treatment is called sumorization.

Adaptations to Water Variations Less than 1% of water taken up by the roots is used in photosynthesis, the rest is transpired. The upward movement of water brings required mineral nutrients to the plants and also causes a cooling effect on plants.

Availability of water is a major selective force in the evolution of the plants ability to respond to moisture stress. Mosses, algae, fungi and lichens have no protective mechanism against water loss because their internal water status tends to match atmospheric moisture conditions. At the condition of water scarcity, their cells sink without disturbing the fine protoplasmic structures and the vital processes are suppressed. With the improvement of moisture condition, they imbibe water and cells resume normal functioning. Such organisms are called **poikilohydric** as they restrict their growth to moist periods. Other plants such as ferns and seed plants are able to maintain stable water balance within limits independent of fluctuations of atmospheric moisture levels and are culled **homohydric**. The ability is supported by vacuoles that store water within the cell, a protective cuticle slowing down evaporation, stomata to regulate transpiration, a combination of osmotic pressure and turgor pressure of water within the cells and the extensive root system.

Responses to water deficits

Leaves respond to water stress by an inward curling or show wilted appearance caused by a lack of turgor in the leaves. A significant response to water deficit is closure of stomata that reduces transpirational water loss, but raises the internal temperature of leaf causing heat stress. Stomatal closure reduces CO2 diffusion ultimately reducing plant growth. Prolonged drought inhibits chlorophyll production causing the leaves to turn yellow. Deciduous trees may prematurely shed their leaves leading to dieback of twigs and branches. Reduction in soil water increases soil temperature reduces root growth and alters mineral uptake from the soil. Such changes make the plants more susceptible to pest attack.

Adaptations to drought

Plants of semi arid and arid regions have evolved many adaptive mechanisms to survive and reproduce in dry environment. Such plants are called xerophytes meaning growing where it is dry (xeric). There are several types of xerophytes adapted in its own way in a dry environment. Xerophytes may be drought resistant perennials usually shrubs such as sage bush having small and hard leaves to reduce water loss and during periods of extreme drought leaves are dropped altogether and new leaves are developed with onset of rain. Such response results in decreased photosynthesis, but some plants maintain a proportion of it by increasing photosynthetic activity in stem. Plants reorient the angle of leaves parallel to sun's rays at the time of water limitation reducing the leaf temperature as well as transpirational water loss. With adequate water, plants orient leaves perpendicular to the sun's rays. Succulents are another kind of xerophytes. Cacti are examples. These plants store and retain water within the plant's fleshy tissues, which it is available for later use. Many succulents have uncoupled the light and dark reactions of photosynthesis in such a way that can keep their stomata closed in the day time and open them taking CO_2 during night to form organic acids and stored in cell vacuoles. In the day light CO_2 yielded by the organic acids is processed in standard C3 photosynthetic fixation. This arrangement is known as **Crassulacean Acid Metabolism (CAM)** after the family crassulaceae, which includes many succulent plants.

Some plants adapt an ephemeral life cycle in which the population survives the dry period as dormant seeds and germinate, grow, flower, set seeds and die in a short period when conditions are fairly moist. The seeds may remain dormant for a number of years, waiting for adequate moisture. Another category of xerophytes is phreatophytes (derived from Greek word meaning well). Some woody plants such as mesquite have deep roots in constant contact with a fringe of capillary water above the ground water table. Mesquite (Prosopis spp.) has a root system reaching down 175 ft. Trees established on perennially dry sites rarely grow tall, but are long lived. They grow slowly with just enough photosynthetic production to achieve microscopic annual growth. By producing little biomass, they reduce drought stress and avoid senescence and death. *Pinus aristata* in known to live for 6000 years or longer on Rocky Mountains of USA. Adaptations to leaves, which reduce water stress are thickening of cell wall, smaller size of stomata, dense vascular system and highly developed palisade tissue These structural features increase the ratio of the exposed surface to the external surface of the leaves. Some leaves are covered by hairs that scatter incoming solar radiation and cool the air close to the leaf surface. Leaves may also be coated with waxes and resins, which reflect the light and reduce the leaf temperature. Many xerophytes are C4 plants, which are able to fix CO_2 at very low concentration. This is an advantage to a xerophyte as the plant can continue photosynthesis even when its stomata are nearly closed and have small amount of CO_2 available in the air spaces. In contrast C3 plants have to keep their stomata open to continue photosynthesis.

Adaptations to water abundance

The plants growing under wet (hydric) condition are called hydrophytes. The concentration of oxygen is lower in water than air. Some sites are wet for a part of the year. The length of time that the soil is saturated is called hydroperiod. On the sites with short hydroperiods of days or weeks, species of mesophytes dominate. As hydroperiod lengthen, specialized hydrophytes can only do well. Excess water around the roots stimulates the plant to resist the movement of water through the roots to the shoots by wilting. Adventitious roots grow horizontally along the oxygenated zone. Shallow root systems make these plants susceptible to wind throw. Hydrophytes are subdivided into following categories;

1. Free floating hydrophytes: They float freely in water bodies on surface with constant contact of water and air. For example Wolffia, Azolla, Lemna, Salvinia and Eichhornia.
2. Rooted hydrophytes with floating leaves: The leaves with long petioles are floating on the water surface with roots fixed in the muds. For example Nymphaea, Nelumbo and Trapa.
3. Submerged floating hydrophytes: They are completely submerged in water with long stems and no roots. For example; *Ceratophyllum* and *Utricularia.*
4. Rooted submerged hydrophytes. They are completely submerged in water and rooted in soil. For example; *Hydrilla, Potamogeton* and *Vallisneria.*
5. Rooted emergent hydrophytes. They grow in shallow water and shoots are partially or completely exposed to air. Root system is well developed and fixed in soil. For example; *Sagittaria, Ranunculus* and *Scirpus*.

Anatomical features of root and shoot show absence of cuticle, thin walled parenchymatous epidermis, well developed cortex with thin walled parenchyma occupied by well developed air cavities called aerenchyma, absence of mechanical tissues and poorly developed vascular tissues. Stems are long, slender and flexible in most of the plants. Vegetative propagation is common. Leaves are thin, long and ribbon shaped or linear or finely dissected in submerged forms. Floating leaves are large, flat with upper surfaces coated with wax. Petioles are long, flexible and mucilaginous. Emergent forms show heterophylly. Leaves of hydrophytes that grow submerged or floating tend to have big internal open spaces (lacunae) where the CO2 given off during respiration and O2 given off during photosynthesis can accumulate and recycled. Cuticle is absent in submerged leaves, but thin and poorly developed in floating and emergent species. Stomata are absent in submerged species, but present on upper side of floating species and both the sides of emergent species. Mesophyll is undifferentiated in submerged leaves, but differentiated into palisade and spongy parenchyma with well developed lacunae in floating and emergent species. There is little water conducting tissues. In floating leaved and emergent hydrophytes, air cavities continue in stem and roots allowing the transport of air from the leaves to the underground or submerged parts.

Under flooded condition, plants are asphyxiated due to low O2 levels. Without sufficient O2 the roots cannot respire aerobically and are shifted to anaerobic metabolism. Under this circumstance, uptake and transport of ions are inhibited leading to reduction in the concentration of nitrogen, phosphorus and potassium in the shoot. Plants accumulate ethylene, which is highly insoluble in water. Under flooded conditions both ethylene diffusion from the roots and O_2 diffusion into the roots is inhibited. This stimulates adjacent cortical cells of the cortex to lyse and form interconnected gas filled chambers called aerenchyma, which allow some exchange of gases between submerged and aerated portions.

Halophytes

High concentrations of salts like sodium chloride, magnesium chloride and magnesium sulphate in soils make it difficult for ordinary plants to obtain sufficient water. Saline soils, which include the soil of semi-arid and arid regions, tidal marshes, coastal dunes and mangrove swamps, are occupied by plants called halophytes or salt plants. Halophytes grow in soil with more than 0.2 per cent salt content. Halophytes extract water from soil with a higher osmotic pressure than normal water. Halophytes have several structural features found in xerophytes, several are succulents. Halophytes have high concentrations of salts in roots and are able to absorb water by osmosis. Halophytes are salt resistant and can carry on metabolic functions in the presence of excess salt within limits. Increased salt tolerance in cells may also involve other solutes such as malate.

Succulent species are able to store water in the cells of leaves and stem and thus dilute the ionic concentration. Even though halophytes tolerate higher salt concentration in their cell sap than non halophytes, they also have ways of getting rid of excess. Several mangroves (Rhizophora spp. and Sonneratia spp.) have salt glands that excrete salts to the surface of the leaves. Some accumulate ions in tissues away from metabolic sites and shed the leaves and their accumulated salts.

Halophytes tend to make their growth after heavy rains, when the salt concentration is lowest and this is also the most favorable time for germination of seeds. Some halophytes are obligates, requiring a saline habitat, while halophytes of coastal marshes and swamps (salt marsh grass, mangroves) grow best at low salinity. Glassworts (Salicornia) grow best at moderate salinity.

Most of the mangrove halophytes produce negatively geotropic roots that come out of the soil to take O_2 directly. Such roots are called pneumatophores, which possess pores for gaseous exchange. In some halophytes, seeds germinate before shedding from parent plants. This characteristic is called vivipary.

Interactions in communities

Key points:

- An ecological **community** consists of all the populations of all the different species that live together in a particular area.
- Interactions between different species in a community are called **interspecific interactions**—*inter-* means "between."
- Different types of interspecific interactions have different effects on the two participants, which may be positive (+), negative (-), or neutral (0).
- The main types of interspecific interactions include **competition** (-/-), **predation** (+/-), **mutualism**, (+/+), **commensalism** (+/0), and **parasitism** (+/-).

Introduction

In nature, animals, plants and microbes do not and cannot live in isolation but interact in various ways to form a biological community. Such interactions are called population interactions. Even in minimal communities, many interactive linkages exist, although all may not be readily apparent.

Interspecific interactions arise from the interaction of populations of two different species. They could be beneficial, detrimental or neutral (neither harm nor benefit) to one of the species or both. Assigning a '+' sign for beneficial interaction, '-' sign for detrimental and 0 for neutral interaction, let us look at all the possible outcomes of interspecific interactions (Table1).

Both the species benefit in mutualism and both lose in competition in their interactions with each other. In both parasitism and predation only one species benefits (parasite and predator, respectively) and the interaction is detrimental to the other species (host and prey, respectively). The interaction where one species is benefitted and the other is neither benefitted nor harmed is called commensalism. In amensalism on the other hand one species is harmed whereas the other is unaffected. Predation, parasitism and commensalism share a common characteristic– the interacting species live closely together.

Table 1: Population Interactions

Species A	Species B	Name of Interaction
+	+	**Mutualism**
–	–	**Competition**
+	–	**Predation**
+	–	**Parasitism**
+	0	**Commensalism**
–	0	**Amensalism**

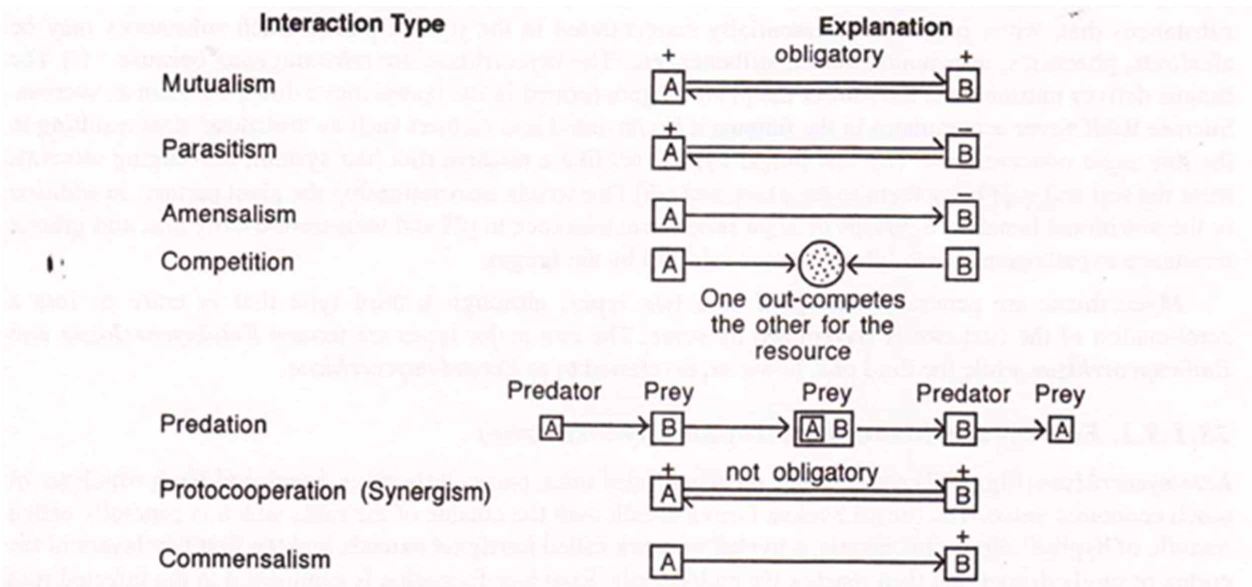


FIG. 33.1. Microbial associations and fundamentals of their interactions. (+) = benefited; (–) = harmed; no (+) or (–) = neither benefited nor harmed.

(i) **Predation:** What would happen to all the energy fixed by autotrophic organisms if the community has no animals to eat the plants? You can think of predation as nature's way of transferring to higher trophic levels the energy fixed by plants. When we think of predator and prey, most probably it is the tiger and the deer that readily come to our mind, but a sparrow eating any seed is no less a predator. Although animals eating plants are categorised separately as herbivores, they are, in a broad ecological context, not very different from predators. Besides acting as 'conduits' for energy transfer across trophic levels, predators play other important roles. They keep prey populations under control. But for predators, prey species could achieve very high population densities and cause ecosystem instability. When certain exotic species are introduced into a geographical area, they become invasive and start spreading fast because the invaded land does not have its natural predators. The prickly pear cactus introduced into Australia in the early 1920's caused havoc by spreading rapidly into millions of hectares of rangeland. Finally, the invasive cactus was brought under control only after a cactus-feeding predator (a moth) from its natural habitat was introduced into the country. Biological control methods adopted in agricultural pest control are based on the ability of the predator to regulate prey population. Predators also help in maintaining species diversity in a community, by reducing the intensity of competition among competing prey species. In the rocky intertidal communities of the American Pacific Coast the starfish Pisaster is an important predator. In a field experiment, when all the starfish were removed from an enclosed intertidal area, more than 10 species of invertebrates became extinct within a year, because of interspecific competition. If a predator is too efficient and overexploits its prey, then the prey might become extinct and following it, the predator will also become extinct for lack of food. This is the reason why predators in nature are 'prudent'. Prey species have evolved various defenses to lessen the impact of predation. Some species of insects and frogs are cryptically-coloured (camouflaged) to avoid being detected easily by the predator. Some are poisonous and therefore avoided by the predators. The Monarch butterfly is highly distasteful to its predator (bird) because of a special chemical present in its body. Interestingly, the butterfly acquires this chemical during its caterpillar stage by feeding on a poisonous weed. For plants, herbivores are the predators. Nearly 25 per cent of all insects are known to be phytophagous (feeding on plant sap and other parts of plants). The problem is particularly severe for plants because, unlike animals, they cannot run away from their predators. Plants therefore have evolved an astonishing variety of morphological and chemical defences against herbivores. Thorns (Acacia, Cactus) are the most common morphological means of defence. Many plants produce and store chemicals that make the herbivore sick when they are eaten, inhibit feeding or digestion, disrupt its reproduction or even kill it. You must have seen the weed Calotropis growing in abandoned fields. The plant produces highly poisonous cardiac glycosides and that is why you never see any cattle or goats browsing on this plant. A wide variety of chemical substances that we extract from plants on a commercial scale (nicotine, caffeine, quinine, strychnine, opium, etc.,) are produced by them actually as defences against grazers and browsers.

(ii) **Competition**: When Darwin spoke of the struggle for existence and survival of the fittest in nature, he was convinced that interspecific competition is a potent force in organic evolution. It is generally believed that competition occurs when closely related species compete for the same resources that are limiting, but this is not entirely true. Firstly, totally unrelated species could also compete for the same resource. For instance, in some shallow South American lakes visiting flamingoes and resident fishes compete for their common food, the zooplankton in the lake. Secondly, resources need not be limiting for competition to occur; in interference competition, the feeding efficiency of one species might be reduced due to the interfering and inhibitory presence of the other species, even if resources (food and space) are abundant. Therefore, competition is best defined as a process in which the fitness of one species (measured in terms of its 'r' the intrinsic rate of increase) is significantly lower in the presence of another species. It is relatively easy to demonstrate in laboratory experiments, as Gause and other experimental ecologists did, when resources are limited the competitively superior species will eventually eliminate the other species, but evidence for such competitive exclusion occurring in nature is not always conclusive. Strong and persuasive circumstantial evidence does exist however in some cases. The Abingdon tortoise in Galapagos Islands became extinct within a decade after goats were introduced on the island, apparently due to the greater browsing efficiency of the goats. Another evidence for the occurrence of competition in nature comes from what is called 'competitive release'. A species, whose distribution is restricted to a small geographical area because of the presence of a competitively superior species, is found to expand its distributional range dramatically when the competing species is experimentally removed. Connell's elegant field experiments showed that on the rocky sea coasts of Scotland, the larger and competitively superior barnacle *Balanus* dominates the intertidal area, and excludes the smaller barnacle *Chathamalu*s from that zone. In general, herbivores and plants appear to be more adversely affected by competition than carnivores.

Gause's 'Competitive Exclusion Principle' states that two closely related species competing for the same resources cannot co-exist indefinitely and the competitively inferior one will be eliminated eventually. This may be true if resources are limiting, but not otherwise. More recent studies do not support such gross generalisations about competition. While they do not rule out the occurrence of interspecific competition in nature, they point out that species facing competition might evolve mechanisms that promote co-existence rather than exclusion. One such mechanism is 'resource partitioning'. If two species compete for the same resource, they could avoid competition by choosing, for instance, different times for feeding or different foraging patterns. MacArthur showed that five closely related species of warblers living on the same tree were able to avoid competition and co-exist due to behavioural differences in their foraging activities.

(iii) **Parasitism**: Parasitism represents the associationship between two living organisms and is of advantage to one of the associates (parasite) but is harmful to the other (host) to a greater or lesser extent. Considering that the parasitic mode of life ensures free lodging and meals, it is not surprising that parasitism has evolved in so many taxonomic groups from plants to higher vertebrates. Many parasites have evolved to be host-specific (they can parasitise only a single species of host) in such a way that both host and the parasite tend to co-evolve; that is, if the host evolves special mechanisms for rejecting or resisting the parasite, the parasite has to evolve mechanisms to counteract and neutralise them, in order to be successful with the same host species. In accordance with their life styles, parasites evolved special adaptations such as the loss of unnecessary sense organs, presence of adhesive organs or suckers to cling on to the host, loss of digestive system and high reproductive capacity. The life cycles of parasites are often complex, involving one or two intermediate hosts or vectors to facilitate parasitisation of its primary host. The human liver fluke (a trematode parasite) depends on two intermediate hosts (a snail and a fish) to complete its life cycle. The malarial parasite needs a vector (mosquito) to spread to other hosts. Majority of the parasites harm the host; they may reduce the survival, growth and reproduction of the host and reduce its population density. They might render the host more vulnerable to predation by making it physically weak.

Parasites that feed on the external surface of the host organism are called ectoparasites. The most familiar examples of this group are the lice on humans and ticks on dogs. Many marine fish are infested with ectoparasitic copepods. *Cuscuta,* a parasitic plant that is commonly found growing on hedge plants, has lost its chlorophyll and leaves in the course of evolution. It derives its nutrition from the host plant which it parasitises. The female mosquito is not considered a parasite, although it needs our blood for reproduction.

In contrast, endoparasites are those that live inside the host body at different sites (liver, kidney, lungs, red blood cells, etc.). The life cycles of endoparasites are more complex because of their extreme specialisation. Their morphological and anatomical features are greatly simplified while emphasising their reproductive potential.

Brood parasitism in birds is fascinating example of parasitism in which the parasitic bird lays its eggs in the nest of its host and lets the host incubate them. During the course of evolution, the eggs of the parasitic bird have evolved to resemble the host's egg in size and colour to reduce the chances of the host bird detecting the foreign eggs and ejecting them from the nest.

(iv) **Commensalism**: This is the interaction in which one species benefits and the other is neither harmed nor benefited. An orchid growing as an epiphyte on a mango branch, and barnacles growing on the back of a whale benefit while neither the mango tree nor the whale derives any apparent benefit. The cattle egret and grazing cattle in close association, a sight you are most likely to catch if you live in farmed rural areas, is a classic example of commensalism. The egrets always forage close to where the cattle are grazing because the cattle, as they move, stir up and flush out from the vegetation insects that otherwise might be difficult for the egrets to find and catch. Another example of commensalism is the interaction between sea anemone that has stinging tentacles and the clown fish that lives among them. The fish gets protection from predators which stay away from the stinging tentacles. The anemone does not appear to derive any benefit by hosting the clown fish.

(V) **Mutualism**: This interaction confers benefits on both the interacting species. Lichens represent an intimate mutualistic relationship between a fungus and photosynthesising algae or cyanobacteria. Similarly, the mycorrhizae are associations between fungi and the roots of higher plants. The fungi help the plant in the absorption of essential nutrients from the soil while the plant in turn provides the fungi with energy-yielding carbohydrates. The most spectacular and evolutionarily fascinating examples of mutualism are found in plant-animal relationships. Plants need the help of animals for pollinating their flowers and dispersing their seeds. Animals obviously have to be paid 'fees' for the services that plants expect from them. Plants offer rewards or fees in the form of pollen and nectar for pollinators and juicy and nutritious fruits for seed dispersers. But the mutually beneficial system should also be safeguarded against 'cheaters', for example, animals that try to steal nectar without aiding in pollination. Now you can see why plant-animal interactions often involve co-evolution of the mutualists, that is, the evolutions of the flower and its pollinator species are tightly linked with one another. In many species of fig trees, there is a tight one-to-one relationship with the pollinator species of wasp. It means that a given fig species can be pollinated only by its 'partner' wasp species and no other species. The female wasp uses the fruit not only as an oviposition (egg-laying) site but uses the developing seeds within the fruit for nourishing its larvae. The wasp pollinates the fig inflorescence while searching for suitable egg-laying sites. In return for the favour of pollination the fig offers the wasp some of its developing seeds, as food for the developing wasp larvae. Orchids show a bewildering diversity of floral patterns many of which have evolved to attract the right pollinator insect (bees and bumblebees) and ensure guaranteed pollination by it. Not all orchids offer rewards. The Mediterranean orchid Ophrys employs 'sexual deceit' to get pollination done by a species of bee. One petal of its flower bears an uncanny resemblance to the female of the bee in size, colour and markings. The male bee is attracted to what it perceives as a female, 'pseudocopulates' with the flower, and during that process is dusted with pollen from the flower. When this same bee 'pseudocopulates' with another flower, it transfers pollen to it and thus, pollinates the flower. Here you can see how co-evolution operates. If the female bee's colour patterns change even slightly for any reason during evolution, pollination success will be reduced unless the orchid flower co-evolves to maintain the resemblance of its petal to the female bee.

(VI). Amensalism:

Amensalism refers to such an interaction in which one microorganism releases a specific compound which has a negative effect on another microorganism. That is, the amensalism is a negative microbe-microbe interaction.

Some important examples are the following:

(i) Antibiotic production by a microorganism and inhibiting or killing of other microorganism susceptible to that antibiotic is the most important example of amensalism. Concentrations of such antibiotics in the bulk of soil or water are certainly small, though there could be a large enough quantity on a micro-habitat scale to give inhibition of nearby microorganisms.

The antibiotics reduce the saprophytic survival ability of pathogenic microorganisms in soil. The antifungal relationship is promoted by antibiotic producing bacteria (e.g., Streptomyces) that are maintained in the fungal gardens. In this case, Streptomyces produces an antibiotic which controls Escovopsis, a persistent parasitic fungus, which can destroy the ant's fungal garden

(ii) Production of ammonia by some microbial population is deleterious to other microbial populations. Ammonia is produced during the decomposition of proteins and amino acids. A high concentration of ammonia is inhibitory to nitrite oxidizing populations of Nitrobacter.

5. Proto-Cooperation (Synergism):

Proto-cooperation (or synergism), like mutualism, represents an association between two microbial populations in which both populations benefit from each other, but it differs from the mutualism in that the association is not 'obligatory'.

Both synergistic populations of microbes are able to survive in their natural environment on their own. Proto-cooperation or synergism allows microbial populations to perform metabolic activities such as synthesis of a product which neither population could perform alone.

Following are few examples:

(i) The Desulfolvibrio bacteria supply H_2S and CO_2 to Chlorobium bacteria and, in turn, the Chlorobium bacteria make sulphate (SO_4^-) and organic material available to Desulfovibrio. Thus the mixture of the two bacterial populations produce much more cellular material than either alone.

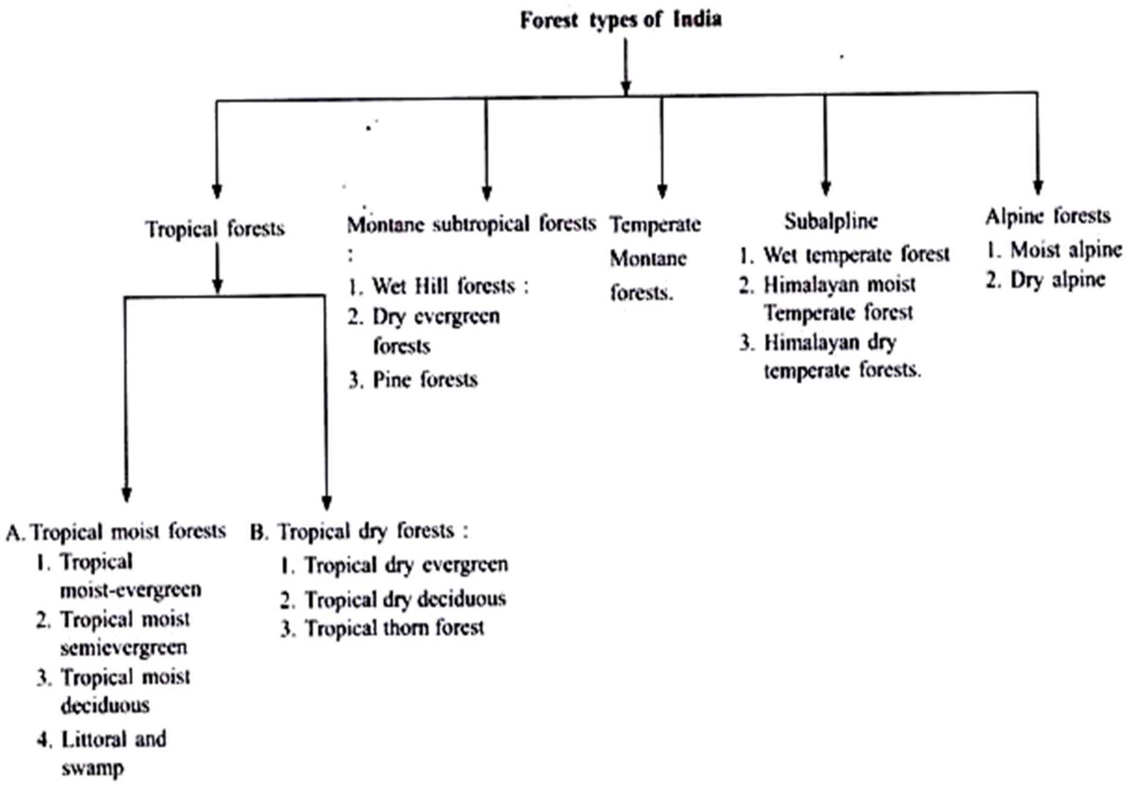
(ii) Nocardia populations metabolize cyclohexane resulting in degradation products that are used by Pseudomonas population. The Pseudomonas species produce biotin and growth factors that are required for the growth of Nocardia.

(iii) Azotobacter populations present in soil fix atmospheric nitrogen if they have a sufficient source of organic compounds. Other soil bacterial populations such as Cellulomonas are able to utilize the fixed form of nitrogen and provide the Azotobacter populations with needed organic compounds.

Forest types of India

Champion (1936) recognized 13 major types of forest in India. Champion and Seth (1968) recognized sixteen types of forest which are listed below.

Hanson (1962) defines forest as "a stand of trees growing close together with associated plants of various kinds".



I. Tropical forest:

A great majority of the forests found in India are of this type. Tropical forests are of two types:

(A) Tropical moist forests.

(B) Tropical dry forests.

A. Tropical moist forests:

These are further classified into the following types on the basis of relative degree of wetness:

(i) Tropical moist evergreen forests,

(i) Tropical moist semi-evergreen forests, and

(iii) Tropical moist deciduous forests.

(iv) Littoral and swamp forests.

(i) Tropical moist evergreen forests:

These are also called tropical rain forests. In India such forests are found in very wet regions receiving more than 250 cm average annual rainfall. These are climatic forests having luxuriantly growing lofty trees which are more than 45 metres in height. The shrubs, lianas (woody climbers) and epiphytes are abundant because of high rainfall. These forests are found in Andaman and Nicobar Islands, Western coasts and parts of Karnataka (N. Canara), Annamalai hills (Koorj), Assam and Bengal. The detail account of this is given in the description of mesophytes.

(ii) Tropical moist semi-evergreen forests:

These forests are found along the western coasts, eastern Orissa and upper Assam where annual rainfall is between 200 and 250 cm. They are characterised by giant and luxuriantly growing intermixed deciduous and evergreen species of trees and shrubs. The important plants in these forests are the species of *Terminalia, Bambusa, Ixora, Dipterocarpus, Garcinia, Sterculia, Mallotus, Calamus, Albizzia, Elettaria, Pothos, Vitis, Shorea, Cinnamomum, Bauhinia, Albizzia,* etc. Orchids, ferns, some grasses and several other herbs are also common.

(iii) Tropical moist deciduous forests:

These cover an extensive area of the country receiving sufficiently high rainfall (100 to 200 cm) spread over most of the year. The dry periods are of short duration. Many plants of such forests show leaf-fall in hot summer.

The forests are found along the wet western side of the Deccan plateau, i.e. Mumbai, N-E. Andhra, Gangetic plains and in some Himalayan tracts extending from Punjab in west to Assam valley in the east. The forests of Southern India are dominated by Teak (*Tectona grandis), Terminalia paniculata, T. bellerica, Grewia tilliaefolia, Dalbergia latifolia, Lagerstroemia, Adina cordifolia*, etc. are the other common species in forests of South India. In north, they are dominated by shal (*Shorea robusta*).

Some other common associates of shal are *Terminalia tomentosa*, *Dellenia* species, *Eugenia species, Boswellia* species and *Mallotus philippensis*. These forests produce some of the most important timbers of India. Grasses become important both in seral stages and in the areas under fire.

(iv) Littoral and Swamp Forests:

Littoral and Swampy forests include the following types:

(1) Beach forests

(2) Tidal forests or Mangrove forests

(3) Fresh water swamp forests.

Beach Forests:

The beach forests are found all along the sea beaches and river deltas. The soil is sandy having large amount of lime and salts but poor in nitrogen and other mineral nutrients. Ground water is brackish, water table is only a few metres deep and rainfall varies from 75 cm to 500 cm depending upon the area. The temperature is moderate. The common plants of these forests are *Casuarina equisetifolia, Borassus, Phoenix, Manilkara littoralis, Callophyllum littoralis, Pandanus, Thespesia, Barringtonia, Pongamia, Cocos nucifera, Spinifex littoreus* and a number of twiners and climbers.

Tidal or Mangrove forests:

Tidal forests grow near the estuaries or the deltas of rivers, swampy margins of Islands and along sea coasts. The soil is formed of silt, silt-loam or silt-clay and sand. The plants are typical halophytes which are characterised by presence of prop roots with well developed knees for support and pneumatophores and viviparous germination of seeds.

Tidal forests one distinguished into the following four types with overlapping constituent species:

(i) Tree mangrove forests

(ii) Low mangrove forests,

(iii) Salt water forests and

(iv) Brackish water forests.

Tree Mangrove forests:

These forests occur on both east and west sea coasts. The best development occurs in Sundarbans. The forest floor is flooded with salt water daily. Plants may attain a height 10-15 metres and form an almost closed evergreen forests. The common trees of these forests are *Rhizophora mucronata, R. conjugata, Avicennia alba, Bruguiera conjugata, B. parviflora, B. caryophylloides, Kandelia candel, Xylocarpus molluccensis, X. granatuns, Ceriops tagal, Avicennia officinalis, Excoecaria agallocha, Sonneratia acida, Lumnitzera racemosa, L. littorea, Aegiceras carniculatum* and two most frequently occurring palms; *Nipafruticans* and *Phoenix paludosa*. In addition to these trees *Acanthus ilicifolius* and other shrubs also grow at places.

Low Mangrove Forests:

These forests grow on soft tidal mud near estuaries, which is flooded by salt water. Forest is dense but the trees with leathery leaves attain maximum height of 3-6 m. The vegetation consists of a few species which show gregarious growth habit. Important tree species are *Ceriops decandra, Avicennia alba, Aegialitis rotundifolia and Excoecaria agallocha*. Besides, a common shrub Acanthus elicifolius and some grasses also occur at places. Low mangrove forests are more developed on east sea coast than on west coast.

Salt water Mangrove Forests:

These forests occur beyond tree mangrove forests in big river deltas where the ground is flooded with tidal water. Silt deposition and salt content in soil are low. Tree height is upto 20 m or so but girth is not large. Forests are dense. Pneumatophores are common. The common plants are *Heritiera minor*, *Excoecaria agallocha*, *Ceriops decandra*, *Xylocarpus molluccensis, Bruguiera conjugata, Avicennia officinalis and Nipa* at places.

Brackish Water Mangrove Forests:

They grow near the river deltas where forest floor is flooded with water at least for some times daily. Water is brackish (salty) but during rains it is nearly fresh. Tree height may reach 30 m or so. Forest is dense. Common species of the forests are *Heritiera minor*, *Xylocarpus molluccensis*, *Bruguiera conjugata*, *Avicennia officinalis*, *Sonneratia caseolaris*, *S. acida*, *Excoecaria agallocha*, *Ceriops decandra Cynometra ramiflora*, *Amoora cuculata*, *Pandanus*, and two palms; *Nipa* and *Phoenix paludosa*.

Fresh Water Swamp Forests:

These forests grow in low lying areas where rain or swollen river water is collected for some time. Water table is near the surface. Important plants include *Salix tetrasperma, Acer, Putranjiva, Holoptelia, Cephalanthus, Barringtonia, Olea, Phoebe, Ficus, Murraya, Adhatoda, Canna* and a variety of grasses.

B. Tropical dry forests.

These are classified into the following types:

(i) Tropical dry evergreen forests,

(ii) Tropical dry deciduous forests, and

(iii) Tropical thorn forests.

(i) Tropical dry evergreen forests:

These forests are found in the areas where rainfall is in plenty but dry season is comparatively longer. The trees are dense, evergreen and short (about 10 to 15 metres high). These forests are found in eastern part of Tamil Nadu, in east and west coasts. The common plant species are much the same as in Tropical moist evergreen forests. Species of *Maba, Calotropis, Pabatta, Feronia, Canthium, Zizyphus, Randia* etc. are most common. Bamboos are absent but grasses are common.

(ii) Tropical dry deciduous forests:

These forests are distributed in the areas where annual rainfall is usually low, ranging between 70 and 100 cm, such as, Punjab, U.P., and Bihar, Orissa, M.P. and large part of Indian peninsula. The largest area of the country's forest land is occupied by Tropical dry deciduous forests. The dry season is long and most of the trees remain leafless during that season.

The forest trees are not dense, 10 to 15 m in height, and undergrowth is abundant. In north, the forests are dominated by shal and in south by teak (*Tectona grandis*). The common constituents of these forests in South are *Dalbergia, Terminalia, Dillenia, Acacia, Pterospermum, Diospyros, Anogeissus, Boswellia, Chloroxylon, Bauhinia, Hardwickia, Gymnosporia, Zizyphus, Moringa, Dendrocalamus*, and so on. The other species of trees and shrubs of Sal dominated forests of northern region are *Terminalia, Semicarpus, Buchnania, Carissa, Modhuca, Acacia, Sterculia, Launea, Salmalia Adina, Bauhinia, Aegle, Grewia, Phyllanthus,* etc.

(iii) Tropical thorn scrubs:

These forests occur in the areas where annual rainfall is between 20 to 70 cm, dry season is hot and very long. They are found in South Punjab, most of Rajasthan and part of Gujarat. The vegetation in these region occurs only along the rivers. The land away from the rivers and devoid of irrigation is mostly sandy and devoid of trees. The vegetation is of open type consisting of small trees (8 to 10 m high) and thorny or spiny shrubs of stunted growth. The forests remain leafless for most part of the year and are sometimes called thorn scrub or scrub jungles.

There is luxuriant growth of ephemeral herbs and grasses during the rainy season. Towards the desert region the vegetation diminishes and in arid parts there is almost no vegetation. The species of *Acacia*, *Cassia*, *Calotropis, Randia, Albizzia*, *Zizyphus*, *Erythroxylon*, *Euphorbia*, *Cordia*, *Prosopis*. *Salvadora, Aegle*, *Gymnosporia*, *Atriplex*, *Grewia*, *Asparagus*, *Berberis*, *Butea*, *Kochia*, *Leptadenia*, *Capparis*, *Adhatoda*, etc. characterise the plant formations of semiarid regions of India.

Champion (1938) named the natural vegetation of desert as tropical thorny forest. Bharucha (1955) divided the Rajasthan desert into the following vegetational zones:

(i) Area of shifting sand dunes at and around Jaisalmer and Bikaner.

(ii) Area of established sand dunes near Jodhpur.

(iii) Sand stone rocks covered by xerophytic plants like *Euphorbia nerifolia*.

(iv) Area of halophytic vegetation.

(v) Sandy-loam soil vegetation.

II. Subtropical montane forests:

These forests are found in the region of fairly high rainfall but where temperature differences between winter and summer are less marked. Winter generally goes without rains. They are found upto the altitude of about 1500 metre in south and up to 1800 metre in the north. In composition, subtropical forests are almost intermediate between tropical forests and temperate forests and a sharp demarcation can seldom be made between tropical and subtropical or subtropical and temperate forests.

These forests have been grouped into the following three types:

(i) Wet hill broad leaved forests,

(ii) Dry evergreen forests, and

(iii) Pine forests.

(i) Wet hill broad leaved forests:

They are found in Mahabaleshwar, Coorg, Karnataka, parts of Assam, Panchmarhi and other parts of M.P. The important plants found in the wet hill forests of south are the species of *Eugenia, Randia, Terminalia, Eleganus, Murraya, Gymnosporia, Atylosia, Ficus, Pterocarpus, Lantana*, etc. while those of the north are *Castonopsis, Calamus, Alnus, Quercus, Betula, Schima phoebe, Cedrella, Garcinia, Populus* etc.

(ii) Dry evergreen forests:

They occupy the foot-hill areas of Himalayas. The common constituents of vegetation are *Acacia modesta, Olea cuspidata*, etc.

(iii) Pine forests:

They are found mostly in western and central Himalayas and in Assam hills. The forests are dominated by species of Pinus (*Pinus khasya* and *P. roxburghii*). Species of *Quercus, Berberis, Carissa, and Bauhinia* may also occur rarely in pine forests.

III. Temperate Montane forests:

These forests occur in the Himalayas at the altitude from 1800 to 3800 metres where humidity and temperature are comparatively low.

Montane forests have been classified into the following three types on the basis of moisture regime:

(i) Montane Wet temperate forest,

(ii) Himalayan Moist temperate forest, and

(iii) Himalayan Dry temperate forest

(i) Montane Wet temperate forests:

These are found in Himalayas extending from Nepal to Assam at the altitude from 1800 to 3000 m, as well as in some parts of South India (Nilgiris). The forests in south are evergreen and are called sholas. The forests are dense with closed canopy and the trees may be 15 to 20 m high. Epiphytes are in abundance. Important plants constituting the vegetation in Eastern Himalayas are species of conifers, *Hopea, Balanocarpus, Elaeocarpus, Artocarpus, Pterocarpus, Myristica, Hardwickia, Salmelia, Dioscoria*. The members of family Compositae, Rubiaceae, Acanthaceae and Leguminosae form the undergrowth.

(ii) Himalayan Moist temperate forests:

These forests develop in the areas of lesser rainfall. The trees are high, sometimes up to 45 metres tall. The dominant elements of vegetation are oak and conifers. Undergrowth is shrubby and consists of deciduous species of *Barberis, Spiraea, Cotaneaster*, etc.

(iii) Himalayan Dry temperate forests:

These forests dominated by Rhododendrons, oaks and conifers from a narrow belt at the altitude from 3000 to 4000 m in the western Himalayas extending from a part of Uttaranchal through Himachal Pradesh and Punjab to Kashmir. The other commonly found species belong to genera *Daphne, Desmodium, Indigofera, Artemisia, Cannabis, Plectranthus, Fraxinus,* several epiphytic mosses, Lichens, etc.

IV. Sub-alpine Forests:

The sub-alpine forests are found throughout Himalayas from Ladakh in the west to Arunachal in the east at the altitude from 2800 m to 3800 m. Annual rainfall is less than 65 cm. but snowfall occurs for several weeks in a year. Strong winds and below 0°C temperature prevail for greater part of the year. Trees are like those of temperate zone. Epiphytic mosses and lichens are in abundance.

Champion (1939) has recognized the following two types of forests in sub-alpine zone:

(a) Sliver Fir-Birch forests which are found on glacial moraines. *Abies spectabilis, Abies densa, Pinus wallichiana, Betula utilis, Quercus semecarpifolia, Pyrus spp. Rhododendrons, Juniperus recurva, J. wallichiana, Berberis, Salix fruticulosa* are common plants of these forests.

(b) Birch-Rhododendron forests which grow on rocky substrata. The common trees are *Betula utilis, Quercus semecarpifolia*, many species of *Rhododendron, Pyrus spp. Acer spp*, *Salix, Juniperus spp* etc.

V. Alpine forests:

Alpine vegetation has been classified into the following three types:

(a) Alpine forests,

(b) Moist Alpine scrubs, and

(c) Dry Alpine scrubs.

(a) Alpine forests:

Plants growing at the altitude from 2900 to 6000 m are called alpine plants. In India, alpine flora occurs in Himalayas between 4500 and 6000 metres. At lower level, alpine forests consist of dwarf trees with or without conifers and at higher level scrubs and only scattered xerophytic shrubs are left to merge with alpine meadows. The common plants of alpine forests are *Abies, Pinus, Juniperus, Betula, shrubby Rhododendrons, Quercus, Pyrus, Salix* etc.

(b) Moist Alpine scrubs:

This type of vegetation is distributed extensively throughout the Himalayas above 3000 metres. It is most often dense and composed of *evergreen dwarf Rhododendron* species, some birch and other deciduous trees. Mosses and ferns cover the ground with varying amounts of alpine shrubs, flowering herbs and ferns. Alpine pastures include mostly mesophytic herbs with very little grasses.

(c) Dry Alpine scrubs:

These are open xerophytic formations spread in U.P., Himachal Pradesh, Punjab and Kashmir. Species belonging to *Artemisia, Potentilla, Kochia, Juniperus* predominate in the vegetation which develops generally on lime stone rock.

Atmosphere: Role, Structure & Composition

- Our planet earth is enveloped by a deep blanket of gases extending several thousands of kilometres above its surface. This gaseous cover of the earth is known as the atmosphere.
- Like land (lithosphere) and water (hydrosphere), the atmosphere is an integral part of the earth.
- Compared to the earth's radius, the atmosphere appears to be only a very thin layer of gases. However, because of the force of gravity, it is inseparable from the earth.
- **Atmospheric pressure:** The air exerts pressure on earth's surface by virtue of its weight. This pressure is called atmospheric pressure. Atmospheric pressure is the most important climatic element. The atmospheric pressure at sea level is **1034 gm per square centimeter.**

Role of Earth's Atmosphere

- The atmosphere contains various gases like oxygen, carbon dioxide, nitrogen etc.
- Plants require carbon dioxide to survive while animals and many other organisms need oxygen for their survival. The atmosphere supplies these life giving gases.
- All life forms need a particular range of temperature and a specific range of frequencies of solar radiation to carry out their biophysical processes. The atmosphere absorbs certain frequencies and lets through some other frequencies of solar radiation. In other words, the atmosphere **regulates the entry of solar radiation**.
- The atmosphere also keeps the temperature over the earth's surface within certain limits. In the absence of the atmosphere extremes of temperature would exist between day and night over the earth's surface.
- Harmful ultraviolet radiation would find its way through, if the atmosphere (ozone in stratosphere to be specific) were absent.
- The atmosphere also takes care of extra-terrestrial objects like meteors which get burnt up while passing through the atmosphere (mesosphere to be precise) due to friction.
- Weather is another important phenomenon which dictates the direction of a number of natural and man-made processes like plant growth, agriculture, soil-formation, human settlements, etc. Various climatic factors join together to create weather.

Composition of Atmosphere

- The atmosphere is a mixture of many gases. In addition, it contains huge numbers of solid and liquid particles, collectively called **'aerosols'.**
- Some of the gases may be regarded as **permanent atmospheric components** which remain in **fixed proportion** to the total gas volume.

- Other constituents vary in quantity from place to place and from time to time. If the suspended particles, water vapour and other variable gases were excluded from the atmosphere, then the dry air is very stable all over the earth up to an altitude of about 80 kilometres.
- The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of 120 km. Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.
- **Nitrogen and oxygen** make up nearly **99%** of the clean, dry air. The remaining gases are mostly **inert** and constitute about 1% of the atmosphere.
- Besides these gases, large quantities of water vapour and dust particles are also present in the atmosphere. These solid and liquid particles are of great climatic significance.
- Different constituents of the atmosphere, with their individual characteristics, are discussed below.

Oxygen

- Oxygen, although constituting only **21%** of total volume of atmosphere, is the most important component among gases. All living organisms inhale oxygen. Besides, oxygen can combine with other elements to form important compounds, such as, **oxides**. Also, **combustion is not possible without oxygen**.

Nitrogen

- Nitrogen accounts for **78%** of total atmospheric volume. It is a **relatively inert gas**, and is an important constituent of all organic compounds. The main function of nitrogen is to **control combustion by diluting oxygen**. It also indirectly helps in oxidation of different kinds.

Carbon Dioxide

- The third important gas is Carbon Dioxide which constitutes only about **03%** of the dry air and is a product of combustion. Green plants, through photosynthesis, absorb carbon dioxide from the atmosphere and use it to manufacture food and keep other bio-physical processes going.
- Being an **efficient absorber of heat**, carbon dioxide is considered to be of great climatic significance. Carbon dioxide is considered to be a very important factor in the **heat energy budget.**
- With increased burning of fossil fuels – oil, coal and natural gas – the carbon dioxide percentage in the atmosphere has been increasing at an alarming rate.

- More carbon dioxide in the atmosphere means more heat absorption. This could significantly raise the temperature at lower levels of the atmosphere thus inducing drastic climatic changes.

Ozone (03)

- Ozone (03) is another important gas in the atmosphere, which is actually a type of oxygen molecule consisting of three, instead of two, atoms. It forms less than **00005%** by volume of the atmosphere and is **unevenly distributed**. It is between **20 km and 25** km altitude that the greatest concentrations of ozone are found. It is formed at higher altitudes and transported downwards.
- Ozone plays a **crucial role in blocking the harmful ultraviolet radiation** from the sun.
- Other gases found in almost negligible quantities in the atmosphere are **argon, neon, helium, hydrogen, xenon, krypton, methane etc.**

Water Vapour

- Water Vapour is one of the most variable gaseous substances present in atmosphere – constituting between **02% and 4%** of the total volume (in cold dry and humid tropical climates respectively). 90% of moisture content in the atmosphere exists within 6 km of the surface of the earth. Like carbon dioxide, water vapour plays a significant role in the insulating action, of the atmosphere.
- It **absorbs not only the long-wave terrestrial radiation (infrared or heat emitted by earth during nights)**, but also a part of the incoming solar radiation.
- Water vapour is the source of precipitation and clouds. On condensation, it releases **latent heat of condensation** —the **ultimate driving force behind all storms**.

Solid Particles

- The Solid Particles present in the atmosphere consist of sand particles (from weathered rocks and also derived from volcanic ash), pollen grains, small organisms, soot, ocean salts; the upper layers of the atmosphere may even have fragments of meteors which got burnt up in the atmosphere. These solid particles perform the function of absorbing, reflecting and scattering the radiation.
- The solid particles are, consequently, responsible for the **orange and red colours** at sunset and sunrise and for the **length of dawn (**the first appearance of light in the sky before sunrise**) and twilight (**the soft glowing light from the sky when the sun is below the horizon, caused by the reflection of the sun's rays by the atmosphere. Dusk: the darker stage of twilight.**)**. The blue colour of the sky is also due to **selective scattering** by dust particles.

- Some of the dust particles are hygroscopic (i.e. readily absorbing moisture from air) in character, and as such, act as **nuclei of condensation.** Thus, dust particles are an important contributory factor in the formation of clouds, fog and hailstones.

Major Greenhouse Gases

Carbon dioxide

- Carbon dioxide is meteorologically a very important gas as it is **transparent to the incoming solar radiation** but **opaque to the outgoing terrestrial radiation**. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the greenhouse effect.

Ozone

- Ozone is another important greenhouse gas. But it is very small proportions at the surface.

Water vapour

- Water vapour is also a variable gas in the atmosphere, which decreases with altitude. Water vapour also decreases from the equator towards the poles.
- In the warm and wet tropics, it may account for four per cent of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than one per cent of the air.
- It also absorbs parts of the insolation from the sun and preserves the earth's radiated heat.
- It thus, acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour also contributes to the stability and instability in the air.

Methane

- One of the most important greenhouse gases. It is produced from **decomposition of animal wastes and biological matter**.

Structure of Atmosphere

- The atmosphere can be studied as a layered entity – each layer having its own peculiar characteristics. These layers are systematically discussed below.

Troposphere

- It is the atmospheric layer between the earth's surface and an altitude of **8 km at the poles and 18 km at the equator.**
- The thickness is greater at the equator, because the **heated air rises to greater heights**.
- The troposphere ends with the **Tropopause**.
- The temperature in this layer, as one goes upwards, falls at the rate of **5°C per kilometer**, and reaches -45°C at the poles and -80°C over the equator at Tropopause (greater fall in temperature above equator is because of the greater thickness of troposphere – 18 km).

- The fall in temperature is called **'lapse rate'.**
- The troposphere is marked by **temperature inversion**, turbulence and eddies.
- It is also meteorologically the most significant zone in the entire atmosphere (Almost all the weather phenomena like rainfall, fog and hailstorm etc. are confined to this layer).
- It is also called the **convective region**, since **all convection stops at Tropopause**.
- The troposphere is the theatre for weather because all cyclones, anticyclones, storms and precipitation occur here, as all water vapours and solid particles lie within this.
- The troposphere is influenced by seasons and jet streams.

Tropopause

- Top most layer of troposphere.
- It acts as a boundary between troposphere and stratosphere.
- This layer is marked by **constant temperatures**.

Stratosphere

- It lies beyond troposphere, up to an altitude of 50 km from the earth's surface.
- The temperature in this layer remains constant for some distance but then rises to reach a level of 0°C at 50 km altitude.
- This rise is due to the **presence of ozone** (harmful ultraviolet radiation is absorbed by ozone).
- This layer is **almost free from clouds** and associated weather phenomenon, making conditions **most ideal for flying aeroplanes**. So aeroplanes fly in lower stratosphere, sometimes in upper troposphere where weather is calm.
- Sometimes, **cirrus clouds** are present at lower levels in this layer.

Ozonosphere

- It lies at an altitude between **30 km and 60 km** from the earth's surface and spans the stratosphere and lower mesosphere.
- Because of the presence of ozone molecules, this layer reflects the harmful ultraviolet radiation.
- The ozonosphere is also called **chemosphere** because a lot of chemical activity goes on here.
- The temperature rises at a rate of **5°C per kilometer** through the ozonosphere.

Mesosphere

- This is an intermediate layer beyond the ozone layer and continues upto an altitude of 80 km from the earth's surface.
- The temperature gradually **falls** to -100°C at 80 km altitude.

- Meteorites burn up in this layer on entering from the space**.**

Thermosphere

- In thermosphere **temperature rises very rapidly** with increasing height.
- **Ionosphere** is a part of this layer. It extends between **80-400 km.**
- This layer helps in **radio transmission**. In fact, radio waves transmitted from the earth are reflected back to the earth by this layer.
- **Person would not feel warm because of the thermosphere's extremely low pressure**.
- The **International Space Station and satellites** orbit in this layer**.** (Though temperature is high, the atmosphere is extremely rarified – gas molecules are spaced hundreds of kilometers apart. Hence a person or an object in this layer doesn't feel the heat)
- **Aurora's** are observed in lower parts of this layer.

Ionosphere

- This layer is located between 80 km and 400 km and is an **electrically charged layer**.
- This layer is characterized by **ionization of atoms**.
- Because of the electric charge, radio waves transmitted from the earth are reflected back to the earth by this layer.
- Temperature again starts increasing with height because of radiation from the sun.

Exosphere

- This is the **uppermost layer** of the atmosphere extending beyond the ionosphere above a height of about 400 km.
- The air is extremely rarefied and the temperature gradually increases through the layer.
- Light gases like **helium and hydrogen** float into the space from here.
- Temperature gradually increases through the layer. (As it is exposed to direct sunlight)
- This layer coincides with space.

Climate change

Climate change, also called global warming, refers to the rise in average surface temperatures on Earth. An overwhelming scientific consensus maintains that climate change is due primarily to the human use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. The gases trap heat within the atmosphere, which can have a range of effects on ecosystems, including rising sea levels, severe weather events, and droughts that render landscapes more susceptible to wildfires.

Current and predicted pattern of global climate change are a major concern in many areas of socio- economic activities, such as agriculture, forestry, etc., and is a major threat for biodiversity and ecosystem function (Lepetz et al., 2009). Climate change is a result from emission of greenhouse gases (e.g. CO_2, CH_4, & N_2O, etc.) in the past century that will cause atmospheric warming (IPCC, 2007). The effects have become particularly obvious over the last 30 years in the natural environment and it will affect all level of life, from the individual, population species community and ecosystem to the eco-region level (Lepetz et al., 2009).

A report from Intergovernmental panel on climate change (IPCC, 2007) shows that CO_2 released from agriculture to large extent comes from microbial decay or burning of plant residue and organic matter. CH_4 produced during fermentation of organic material, emitted from ruminant animals, stored manure (waste), and rice farming under flooded condition, etc. N_2O generated by microbial transformation of nitrogen in soil, manures and often, enhanced where there is high availability of N, especially under wet condition (Smith et al., 2007). The production of greenhouse gases from agriculture is complex and heterogeneous, but active management of agricultural system can give possibilities for mitigation (IPCC, 2007).

General Overview of Climate Change

Global warming and climate change is largely attributed to emission of GHGs from natural or anthropogenic sources and changes in albedo (reflection of radiation from different surfaces to the atmosphere that causes warming or cooling of the planet, with value between 0-1 http://en.wikipedia.org/wiki/Albedo). Climate change is one of the main drivers of terrestrial biotic change and has different effects, such as disturbances and loss of habitat, fragmentation, and increasing the incidence of photogenes. In addition, following a change in climate parameters (precipitation change, snow cover, humidity, sea level etc.) there is variation in exchange of different activities in symbiotic, prediction, parasitic and mutualistic relationships (Lepetz et al., 2009). As global mean temperature rise, it causes positive or negative effects on different processes and activities in earth systems (IPCC, 2007). These effects may affect ecosystem services, biodiversity, species composition, plant growth and productivity.

Effects of climate change on ecosystems and ecosystem services

An ecosystem is a dynamic complex system of plant, animal, and microorganism communities and the non-living environment interacting with each other as a functional unit. Ecosystem services are the benefits that people get from ecosystems, like food, forest products, water quality and quantity, soil conservation, biodiversity, recreation, and other cultural values. Ecosystems and ecosystem services affected by global climate change, both directly and indirectly. Many studies particularly on agricultural crops and forest shows that the enhanced atmospheric CO_2 directly increase productivity, because higher ambient CO_2 concentration stimulates net photosynthetic activity which have been called ´CO2-fertilization` effect. Transpiration decreases through a partial stomatal closure resulting in increased water use efficiency of plants at least at a leaf scale; nevertheless, there are considerable differences between different species regarding their response. Some species in terrestrial ecosystems may in the long-term indirectly react negatively, perhaps fatal, to increased CO_2 concentration. The indirect responses of ecosystems are due to the effect of elevated CO_2 concentration is through effect on climate, such as change in temperature or radiation, humidity, precipitation or other climate variables. In most cases, this situation (the change in climate variables) can cause an impact on ecosystems (Bolin et al., 1989).

Precipitation Change

Global warming causes higher evaporation rates and therefore, higher precipitation rates, but a large general increase in precipitation is not expected, there will be some regions on the globe where the precipitation will increase and others where it will decrease. According to IPCC (2007), more rain expected in the equatorial belt (humid tropics) and at higher-latitudes. While less precipitation projected at mid-latitudes, semiarid areas and dry tropics. The spatial extent of severe soil moisture deficits and frequency of short-term drought (due to shortage and absence of expected rain water for a short period of time) is expected to double until late 21st century and long-term drought become three times more common especially in regions with less precipitation (IPCC, 2007 and Fussel, 2009).

Rise in Temperature

Warming of the earth do not uniformly distributed over the world; continents show more rapid temperature increase as compared to oceans. Temperature change will have very different impacts on vegetation and ecosystem productivity, structure and composition depending on the actual temperature range at the location (Morison & Lawrol 1999). Global temperature has increased about 0.2oC per decade for the past 30 years and warming is larger in the western equatorial pacific than in the eastern equatorial pacific over the past century (IPCC, 2007).

Plant Responses to Climate change

Plants are grouped in to ´C3`, ´C4` and ´CAM` plants according to their photosynthetic metabolic pathways. Around 95 % of the world plant biomass grouped in ´C3` plant species (e.g. wheat, rice, fruits & vegetables), C4 (e.g. maize or corn, sugarcane & sorghum) and CAM (e. g. Pineapple). These divisions into groups largely based on the enzymes involved in photosynthetic fixation of CO_2, namely Rubisco, PEP carboxylase and to some extent carbonic anhydrase, which are significantly different in their response to CO_2 enrichment. CO_2 together with other minerals can activate Rubisco by binding at a non-catalytic site on the enzyme protein. The process of photorespiration rate is high in C3 plants and the relative proportion of CO_2 and O_2 inside the leaf determines the rate of photorespiration. In contrast, PEP carboxylase in C4 plants not inhibited by O_2 and thus photorespiration is negligible. PEP carboxylase also has a higher effective affinity for CO_2 than Rubisco in the absence of O_2. Therefore, we would expect higher atmospheric CO_2 concentrations to increased photosynthesis and growth of C3 plants but not to the same extent, if any, in C4 plants (Bolin, 1989). The result from experiments done on wild grass species shows that under elevated CO_2 condition both C3 and C4 species show increase in the total plant biomass of 44% and 33% respectively, the increased in C3 species was greater in tiller formation whereas in C4 was greater in leaf area. Net CO_2 assimilation rates (A), that means (flux of CO_2 between leaf and atmosphere through photosynthesis) increased in both C3 and C4 species with 33% and 25% respectively, while, stomatal conductance (Gs)(the ability of CO_2 entering, or water vapor exiting through the stomata) decreased for C3 and C4 species by 24% and 29%, respectively (Wand et al., 1999).

Responses of field crops to climate change

Elevated [CO_2] leads plants to produce a larger number of mesophyll cell, chloroplasts, longer stems and extended length, diameter and number of large roots, forming good lateral root production with different branching patterns; in some agricultural food crops, resulting in increasing root to shoot ratios under elevated [CO_2] (Qaderi & Reid, 2009). The potential of crop productivity increased under an increased in local average temperature range of 1-3 ^{o}C, but it decreased above this range (IPCC, 2007), probably the reason could be low vernalization, shortened phenological phases decrease in photosynthesis rate, and increased transpiration. (Qaderi & Reid, 2009).

Responses of forest trees to climate change

Different processes in plants or forest ecosystems and their interaction with climate variability is complex, due to different response of physical, biological, and chemical processes. An increase in the ambient CO_2 concentration could reduce the opening of stomata required to allow a given amount of CO_2 to enter in the plant that might reduce transpiration of the trees. These could increase the efficiency of water use by forest plants and increase productivity to some extent (Bolin et al., 1989). Trees are capable of adjusting to a warmer climate, although the response expected from species are different and the effect on photoinhibition and photorespiration are more difficult to generalize (Saxe et al., 2001). As forest trees are characterized by the C3 photosynthetic path way their productivity and demand for nutrient is highly affected by atmospheric CO2 concentration and temperature. The total productivity expected from trees (especially from trees with indeterminate growth) growing under elevated CO2 is larger than estimated in crops (Lukac et al., 2010). Estimated increased production from trees is higher than crops only achieved especially if the combination of absorption and increased nutrient use efficiency is attained (Tylianakis et al., 2008).However, the long-term response of forest to rising level of [CO2] is still uncertain. The current over all response of trees is positive and results from a review of 49 papers on effects of elevated CO2 on different tree species shows that net primary production (NPP, photosynthesis minus plant respiration) on average increased with 23 % at an elevated CO2 concentration of 550 ppm as compared with 370 ppm (Norby et al., 2005). Whereas, enhanced in temperatures can lead to heat and more water logging stress in bogs and cause more severe heat, drought and photo-inhibition stress periods in temperate bog and forest ecosystems (Niinemets, 2010).

Photosynthesis and plant respiration processes

Respiration can be highly affected by temperature (Atkin et al., 2005), and its rate is determined by status of carbohydrate and supply of adenylate (enzyme catalyzing the conversion processes). The sucrose content of the tissue can govern the capacity of mitochondrial respiration (Farrar & Williams, 1991), and mitochondrial respiration plays a great role in growth and survival of plants (Atkin et al., 2005). One would expect at least a short period increases in respiration rate from parts of plants those show increased growth and assimilation due to elevated [CO2], that is source leaves, individual sink tissue (fruit, seed, steam, root etc.) and total sink tissue. Nevertheless, a few reports concluded that long-term treatment with increased concentration of CO2 resulted in declined whole-plant respiration (Farrar & Williams, 1991). Whereas, result of a few other experiments show that a short-term increase in temperature on plants growing in cold climate areas such as Arctic have resulted in greater potential impact on plant respiration than in plants growing in warmer areas (tropics) (Atkin & Tjoelker, 2003). One of the reasons might be that tropical plants more acclimate to higher temperatures than the Arctic cold area plants.

Agriculture and climate change

Agriculture contributes to climate GHGs emission (see Chapter 2) and highly affected by change in climate parameters. In an intensive farming, we expect high greenhouse gases emission because of using high amount of inputs and chemicals, due to these changes of human activity natural divers and climate change impacts varies accordingly in different part of the world.

Vulnerability to climate change depends not only on physical and biological responses but also on socio economic characteristics. Low- income population especially those who cultivate crops under rain fed and non- irrigated agriculture systems in dry lands, arid and semi-arid areas highly affected by severe hard ship due to climate change (Grasty, 1999).

Climate variables and productivity

According to suggestion of fourth assessment report of IPCC, (2007) The overall impacts of higher temperatures on crop responses at the plot level, without considering changes in the frequency of extreme events, moderate warming. (I.e. in the first half of this 21st century) may benefit in crop and pasture productivity in temperate regions, while it may reduce productivity in tropical and semi-arid regions. Modelling studies indicate small beneficial effect in temperate corresponds to local mean temperature increases in 1-3oC with association of an increased in CO2 and rainfall changes. In contrast, models show that tropical regions show a negative yield impacts for major crops with moderate rise in temperature (1-2oC), but further warming projected in all regions in the end of twenty-first century results in the increased on negative impacts (Tubiello et al., 2008).

Direct effects of climate change on food crops

Food production can be negatively or positively affected following variation in weather patterns (short winter, long summer, earlier spring) and other extreme weather events such as drought (change in amount and timing of precipitation), flooding, etc. In addition, illegal deforestation can cause reduction in crop production, due to its effect on environmental services such as crop pollination, genetic resources, clean air and water supply, soil fertility and erosion, as well as pests and pathogen control (Cerri et al., 2007).

Indirect effect of temperature

Several studies shown that soil warming can affect availability of nutrient, increase soil N mineralization and nitrate leaching, organic matter decomposition, and a slight temperature increase can produce a significant enhancement of activities. An increase in N mineralization in soil can be predicted under favourable moisture conditions and substrate availability, mainly in those ecosystems where temperature is a limiting factor, which leads to increased NPP (net primary production), increased N demand and ultimately to decrease N availability in the soil. An increasing temperature will also speed up the release of nutrients locked up in organic soil fraction and minerals, while decreasing soil moisture may limit this process. A higher rate of weathering of nutrient rich rocks generally leads to higher base saturation of the soil and maintain higher soil pH, both characteristics favourable to plant growth. While elevated CO_2 not thought to have a direct effect on weathering (Lukac et al., 2010).

Plant species distribution limited not only by their absolute limits of survival, but also through competition within species, which species acclimate and grow better in a given climate. In the context of population extinction, it is important to consider the effects during climate events. Temporal variability in environment commonly believed to increase the probability of population extinction, particularly if environmental variability increases due to climate change. Some evidence suggest that climate change already drives the extinction of rear edge plant populations leading to a distribution with a ´trailing` edge. Some desert trees like Aloe dichotoma in southern Africa the trailing edge of the range, making populations showed negative demographic rates, and strongly positive rates observed at the leading edge of the range making population growth rate sensitive and use full indicator of incipient change in range (Thuiller et al., 2008).

Impacts of temperature × [CO_2] interaction on plant processes

There are many processes in plant growth, affected by interaction of both enhanced temperature and carbon dioxide, in processes that determine carbon balance in the shorter term, from the long time scales of development and growth, which together lead to accumulation of biomass and yield. The two main reasons to expect progressively increasing CO_2 responsiveness of plant carbon balance at higher temperatures are 1) the decreased ratio of photosynthesis to photorespiration and 2) the decreased ratio of gross photosynthesis to dark respiration in warmer conditions (Morison & Lawlor, 1999).

The effect of elevated CO_2 on photosynthetic reactions are more pronounced in high temperature, e.g. around 20oC than at 10oC. Some predictions indicate that future increase in temperature may increase root mortality more in N-rich soils in temperate forests than in Npoor soils in boreal forests areas with important implications for the cycling between plant and soil (Lukac et al., 2010). Some (unpublished) studies found that changes in activation state and catalytic constant occur due to both CO_2 and temperature, and there were an interaction, which affected the photosynthetic rate demonstrating the underlying complexity of the photosynthetic regulation mechanisms (Morison & Lawlor, 1999).

Ecosystem

An **ecosystem** can be defined as a functional unit of nature, where living organisms interact among themselves and also with the surrounding physical environment. The term was coined by **Arthur Tansely** (1935). Mobius called it **biocoenosis.**

Types: It is convenient to divide ecosystem into two basic categories, namely the **terrestrial** and the **aquatic**. Forest, grassland and desert are some examples of terrestrial ecosystems; pond, lake, wetland, river and estuary are some examples of aquatic ecosystems. Crop fields and an aquarium may also be considered as man-made ecosystems.

Structure: Interaction of **biotic** and **abiotic** components result in a physical structure that is characteristic for each type of ecosystem.

1. **Biotic Components:** Different types of living organisms present in an ecosystem are called biotic components. They are linked together through **food chains** and **food webs**. An ecosystem contains three biotic components- **Producers, Consumers and Decomposers.**
   a. **Producers or Autotrophs:** They are able to manufacture organic food from inorganic raw materials. The various producers are green plants, algae, cyanobacteria and some bacteria. In aquatic ecosystems, main producers are floating minute autotrophs called **Phytoplanktons.**
   b. **Consumers:** They are mostly animals which feed on other organisms for obtaining nourishment. They are also called **Phagotrophs. Consumers are** of following types:
      i. **Primary or First Order:** These directly feed on Producers and are therefore also called herbivores. These are called **key industry animals** as they convert plant matter into animal matter. e.g., Rabbit
      ii. **Secondary or Second Order or Primary Carnivores:** These prey on Herbivores. e.g., Fox
      iii. **Tertiary or Third Order or Secondary Carnivores:** These feed on primary carnivores. Wolf
      iv. **Top Carnivores:** These are not eaten by others. e.g., Lion
   c. **Decomposers or Reducers:** These are saprotrophs which obtain nourishment from organic remains. These are called mineralisers and are important for biogeochemical cycling.

Trophic Levels

They are levels at which organisms obtain their food. These are recognized as:

1. First trophic level or T1: It consists of producers.
2. Second trophic level or T2: It consists of herbivores.
3. Third trophic level or T3: It consists of Primary carnivores.
4. Fourth Tropic Level or T4: It consists of secondary carnivores.

5. Fifth tropic Level or T5: It consists of Tertiary carnivores.
6. Sixth tropic level or T6: It is occupied by decomposers.

2. **Abiotic Components:** They are the factors and materials of the physical environment. These include air, water, soil, light etc.

Ecosystem Functions

The four most important functional aspects of an ecosystem are:

(i) Productivity

(ii) Decomposition

(iii) Energy flow and

(iv) Nutrient cycling.

PRODUCTIVITY

It is the amount of energy fixed by an ecosystem or its component per unit time per unit area. Productivity is of two types, Primary and Secondary.

a. **Primary productivity** is defined as the amount of biomass or organic matter produced per unit area over a time period by plants during photosynthesis. It is expressed in terms of weight (g^{-2}) or energy ($kcal\ m^{-2}$). The rate of biomass production is called **productivity**. It is expressed in terms of $g^{-2}\ yr^{-1}$ or ($kcal\ m^{-2}$) yr^{-1} to compare the productivity of different ecosystems. It can be divided into gross primary productivity (GPP) and net primary productivity (NPP). **Gross primary productivity** of an ecosystem is the rate of production of organic matter during photosynthesis. A considerable amount of GPP is utilized by plants in respiration. Gross primary productivity minus respiration losses (R), is the **net primary productivity** (NPP).

$$GPP – R = NPP$$

Net primary productivity is the available biomass for the consumption to heterotrophs (herbiviores and decomposers).

b. **Secondary productivity** is defined as the rate of formation of new organic matter by consumers.

DECOMPOSITION

Decomposers break down complex organic matter into inorganic substances like carbon dioxide, water and nutrients and the process is called **decomposition**. Dead plant remains such as leaves, bark, flowers and dead remains of animals, including fecal matter, constitute **detritus**, which is the raw material for decomposition. The important steps in the process of decomposition are fragmentation, leaching, catabolism, humification and mineralisation.

Detritivores (e.g., earthworm) break down detritus into smaller particles. This process is called **fragmentation.** By the process of **leaching,** water soluble inorganic nutrients go down into the soil horizon and get precipitated as unavailable salts. Bacterial and fungal enzymes degrade detritus into simpler inorganic substances. This process is called as **catabolism**. Humification and mineralisation occur during decomposition in the soil. **Humification** leads to accumulation of a dark coloured amorphous substance called **humus** that is highly resistant to microbial action and undergoes decomposition at an extremely slow rate. Being colloidal in nature it serves as a reservoir of nutrients. The humus is further degraded by some microbes and release of inorganic nutrients occurs by the process known as **mineralisation**.

ENERGY FLOW

Except for the deep sea hydro-thermal ecosystem, sun is the only source of energy for all ecosystems on Earth. Of the incident solar radiation less than 50 per cent of it is **photosynthetically active radiation** (PAR). We know that plants and photosynthetic and chemosynthetic bacteria (autotrophs), fix suns' radiant energy to make food from simple inorganic materials. Plants capture only 2-10 per cent of the PAR and this small amount of energy sustains the entire living world. So, it is very important to know how the solar energy captured by plants flows through different organisms of an ecosystem. All organisms are dependent for their food on producers, either directly or indirectly. So a unidirectional flow of energy from the sun to producers and then to consumers takes place.

Storage and expenditure of energy in ecosystems is governed by the first two laws of thermodynamics. The **first law of thermodynamics** states that energy can neither be created nor destroyed but it can be transformed from one form into another. Thus energy of sunlight is changed into chemical energy of food and heat. As food, energy passes from one trophic level to the next. According to second law of thermodynamics no transformation of energy occurs unless and until it is accompanied by dissipation of energy from concentrated to dispersed form. Energy of food is in concentrated form while it is highly dispersed form in heat. Thus, the transfer of food energy from one trophic level to another is accompanied by loss of major part of food energy as heat. The important point to note is that the amount of energy decreases at successive trophic levels. When any organism dies it is converted to detritus or dead biomass that serves as an energy source for decomposers. Organisms at each trophic level depend on those at the lower trophic level for their energy demands. Each trophic level has a certain mass of living material at a particular time called as the **standing crop**. The standing crop is measured as the mass of living organisms (**biomass)** or the number in a unit area. The transfer of energy follows 10 per cent law (Lindeman

1942). It states that only 10 per cent of the energy is transferred to each trophic level from the lower trophic level. 90% of the biomass energy is dissipated.

NUTRIENT CYCLING

The amount of nutrients, such as carbon, nitrogen, phosphorus, calcium, etc., present in the soil at any given time, is referred to as the **standing state**. It varies in different kinds of ecosystems and also on a seasonal basis. What is important is to appreciate that nutrients are never lost from the ecosystems; they are recycled time and again indefinitely. The movement of nutrient elements through the various components of an ecosystem is called **nutrient cycling**. Another name of nutrient cycling is **biogeochemical** cycles (bio: living organism, geo: rocks, air, and water). Nutrient cycles are of two types: (a) **gaseous** and (b) **sedimentary.** The reservoir for gaseous type of nutrient cycle (e.g., nitrogen, carbon cycle) exists in the atmosphere and for the sedimentary cycle (e.g., sulphur and phosphorus cycle), the reservoir is located in Earth's crust. The function of the reservoir is to meet with the deficit which occurs due to imbalance in the rate of influx and efflux.

Carbon Cycle

Carbon constitutes 49 per cent of dry weight of organisms and is next only to water. 71 per cent carbon is found dissolved in oceans. This oceanic reservoir regulates the amount of carbon dioxide in the atmosphere. Fossil fuels also represent a reservoir of carbon. Carbon cycling occurs through atmosphere, ocean and through living and dead organisms. According to one estimate 4×10^{13} kg of carbon is fixed in the biosphere through photosynthesis annually. A considerable amount of carbon returns to the atmosphere as CO2 through respiratory activities of the producers and consumers. Decomposers also contribute substantially to CO2 pool by their processing of waste materials and dead organic matter of land or oceans. Some amount of the fixed carbon is lost to sediments and removed from circulation. Burning of wood, forest fire and combustion of organic matter, fossil fuel, and volcanic activity are additional sources for releasing CO2 in the atmosphere. Human activities have significantly influenced the carbon cycle. Rapid deforestation and massive burning of fossil fuel for energy and transport have significantly increased the rate of release of carbon dioxide into the atmosphere.

Phosphorus Cycle

Phosphorus is a major constituent of biological membranes, nucleic acids and cellular energy transfer systems. Many animals also need large quantities of this element to make shells, bones and teeth. The natural reservoir of phosphorus is rock, which contains phosphorus in the form of phosphates. When rocks are weathered, minute amounts of these phosphates dissolve in soil solution and are absorbed by the roots of the plants. Herbivores and other animals obtain this element from plants. The waste products and the dead organisms are decomposed by phosphate-solubilising bacteria releasing phosphorus. Unlike carbon cycle, there is no respiratory release of phosphorus into atmosphere.

The other two major and important differences between carbon and phosphorus cycle are firstly, atmospheric inputs of phosphorus through rainfall are much smaller than carbon inputs, and, secondly, gaseous exchanges of phosphorus between organism and environment are negligible.

Nitrogen Cycle

The nitrogen cycle is the shift between different chemical forms of nitrogen through biologic, physical, and geologic processes on Earth. Nitrogen is an essential element for all living things. It is a building block of biologic molecules such as proteins and nucleic acids. The majority of nitrogen on the planet is in the form of molecular nitrogen in the air. Only certain bacteria can convert nitrogen into biologic molecules that occur mainly inside living cells. Humans are interfering with the nitrogen cycle by making nitrogen fertilizers and by oxidizing atmospheric molecular nitrogen through the extensive burning of fossil fuels.

Nitrogen is one of the key elements in human activities and in biologic, physical, chemical, and geo- logic processes. Estimates show that more than 20 million tons of nitrogen exists on every square mile of the planet. The atmosphere contains up to 78 per- cent molecular nitrogen (N2), and this nitrogen is mainly cycling through biologic processes. Four major nitrogen transformation (biologic) processes exist in nature: nitrogen fixation, ammonification, nitrification, and denitrification.

Nitrogen Fixation

The utilization of molecular nitrogen (N_2) by particular bacteria is called **nitrogen fixation**. Some of these bacteria (Rhizobium) live in symbiosis with certain legume plants and others are free-living bacteria such as cyanobacteria or Azotobacter. Legume plants include soybeans, clover, alfalfa, beans, and pears. Symbiotic nitrogen fixing cyanobacteria provide nitrogen to other plant species such as the water-fern *Azolla* and *liverworts* and *Cycads.* The nitrogen fixation or reduction of N_2 to NH_3 (ammonia) is a complicated, multistep process (N_2 + 8e- + 8H+ + 16ATP → $2NH_3$ + H_2 + 16ADP + 16P). Ammonia produced by this process is further con- verted to proteins, nucleic acids (DNA), and other nitrogen-containing organic molecules (NH_3 → ni- trogenous organic molecules: proteins, nucleic acids, and so forth). The nitrogen fixation is catalyzed by the enzyme nitrogenase. Nitrogenase is sensitive to molecular oxygen (O_2). Nitrogen-fixing organisms possess a number of morphological and biochemical modi- fications designed to protect enzymes from oxygen inactivation. For example, the bacterium Rhizobium controls the oxygen level in cells by the protein leghemoglobin, which catches oxygen. In the case of cyanobacteria, there are specialized cells (called heterocysts) for nitrogen fixation. Heterocysts show high rates of respiration, which ultimately reduces oxygen levels in these cells. Nitrogen fixation is an energy-consuming process, which explains why cyanobacteria normally have only 5 to 10 percent of heterocysts among their cells. To maintain nitrogen fixation, other cyanobacterial cells (vegetative cells) work to generate enough energy for heterocysts. All life on Earth depends on nitrogen fixation because the main reservoir of nitrogen on Earth is in the air as molecular nitrogen (N_2). The main path of nitrogen from the air into biologic nitrogen-containing molecules of different organisms is through nitrogen fixation. Nitrogen fixation also is of enormous importance to agriculture because it supports the nitrogen needs of many crops. This process was discovered by Russian microbiologist Sergei Winogradsky. Apart from natural nitrogen fixation, the indus- trial Haber-Bosch process converts molecular nitrogen to ammonia. In this process nitrogen fertilizers are made for agriculture. Haber-Bosch is an energy-consuming route, and the process of manufacturing nitrogenous fertilizers consumes up to 50 percent of the energy input in modern agriculture.

Ammonification

Ammonification is the process of making am- monia or ammonium ions (NH_4^+) by living things. Ammonium ions are produced as a waste of such animals as fish and during decomposition of organic nitrogen wastes by bacteria and by metabolism of some bacteria. Bacteria, for example, can convert ni- trate into ammonia in soils or in the human gut. Globally, only a small amount (15 percent) of nitrogen reaches the atmosphere as ammonia, com- pared with N_2 and N_2O. The majority of ammonium ions are quickly consumed in soil and water by mi- croorganisms and plants. At different points in the food web, ammonium ions are returned to the environment.

Nitrification

Nitrification is caused by the sequential action of two separate groups of soil bacteria: the ammonia oxidizing bacteria (the Nitrosifyers) and the nitrite oxidizing bacteria (nitrifying bacteria). These bacteria obtain energy by consuming nitrogen compounds and can feed only on inorganic compounds. The end product of nitrification is nitrate, a valuable nitrogen source for plants. Nitrification is a two-step process. Nitrosifyers, such as the bacterium Nitrosomonas, convert ammonium ion into nitrite first ($NH_4^+ + O_2 \rightarrow NO_2 + H_2O + H^+$). Later, nitrifying bacteria, such as the bacterium Nitrobacter, oxidize nitrite into nitrate ($NO_2 + O_2 \rightarrow NO_3$). Nitrosifyers and nitrifying bacteria are common in soil and water. They live especially in areas where ammonia is present in high amounts, such as sites of ammonification and in wastewater and manure. Nitrification does not contribute significantly to agriculture. Although liked by plants, nitrate is not always available for plants in soils. Nitrate is quickly consumed by microorganisms during denitrification. Additionally, one species of *Archaea* (microorganisms similar to bacteria) undergoes nitrification by oxidizing ammonia in the oceans.

Denitrification

The conversion of nitrate into gaseous nitrogen compounds such as N_2O, NO, and N_2 by different bacteria in soils is called denitrification or nitrate reduction. Bacteria use nitrate as a substitute for oxygen during respiration and convert it to different nitrogenous compounds according to the following chain of reactions: $NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2$. Eventually, nitrogen is released into the atmosphere as N_2O and NO or as N_2. Simultaneously, bacteria decompose significant amounts of organic matter within the soil. Denitrification has a negative effect on agriculture, as it removes nitrogen from soils. In contrast, denitrification can be useful in wastewater treatment.

Food Chain

The sequence of trophic levels through which food travels while passing from producers to ultimate consumers is called food chain. In food chain the phenomenon of eat and be eaten operates.

Types of food chains: Food chains are of three types:

1. **Grazing Food Chain (GFC):** It is common food chain where producers are eaten by herbivores, herbivores by carnivores and the latter by higher order carnivores.
2. **Parasitic Food Chain**: It terminates at the level of parasites. It is also called **subsidiary or accessory food chain.**

3. **Detritus food chain:** The **detritus food chain** (DFC) begins with dead organic matter. It is made up of **decomposers** which are heterotrophic organisms, mainly fungi and bacteria. They meet their energy and nutrient requirements by degrading dead organic matter or detritus. These are also known as **saprotrophs** (*sapro:* to decompose). Decomposers secrete digestive enzymes that breakdown dead and waste materials into simple, inorganic materials, which are subsequently absorbed by them.

Food Web

It is interlocking of two or more types of food chains at different tropic levels.

Features of Food Web:

1. A food web is never straight.
2. It consists of a number of interconnected food chains.
3. A predator can operate at different positions.
4. It provides for alternate sources of food.
5. No species is expoited beyond the degree of its recovery.
6. Food webs provide stability to the ecosystem.

Ecological Pyramids:

The graphic representation of various ecological parameters at the successive tropic levels of food chains with producers at the base, top carnivores at the apex and intermediate levels in between is called Ecological Pyramid. These were first prepared by Elton (1927). Hence, they are also called Eltonian Pyramids. The relationship is expressed in terms of number, biomass or energy. The base of each pyramid represents the producers or the first trophic level while the apex represents tertiary or top level consumer. The three ecological pyramids that are usually studied are **(a) pyramid of number; (b) pyramid of biomass and (c) pyramid of energy**.

In most ecosystems, all the pyramids, of number, of energy and biomass are upright, i.e., producers are more in number and biomass than the herbivores, and herbivores are more in number and biomass than the carnivores. Also energy at a lower trophic level is always more than at a higher level. However, there are exceptions to this generalization. A tree supports a number of herbivores or frugivorous birds. Each bird has a number of ectoparasites and endoparasites. Thus, this pyramid of number is inverted. Similarly, the pyramid of biomass in sea is also generally inverted because the biomass of fishes far exceeds that of phytoplankton.

Pyramid of energy is always upright, can never be inverted, because when energy flows from a particular trophic level to the next trophic level, some energy is always lost as heat at each step.

Ecological Succession:

An important characteristic of all communities is that composition and structure constantly change in response to the changing environmental conditions. This change is orderly and sequential, parallel with the changes in the physical environment. These changes lead finally to a community that is in near equilibrium with the environment and that is called a **climax community**. The gradual and fairly predictable change in the species composition of a given area is called **ecological succession**. During succession some species colonise an area and their populations become more numerous, whereas populations of other species decline and even disappear.

The entire sequence of communities that successively change in a given area are called **sere(s).** The individual transitional communities are termed **seral stages or seral communities.**

Types of Successional communities:

1. **Pioneer Community**: It is the first community that develops from the earliest colonizers over a bare area.
2. **Seral or Transitional Communities**: They are communities that develop on an area during biotic succession in between pioneer and climax communities.
3. **Climax Community**: It is stable, self-perpetuating biotic community and is also called **climatic climax community.**

Types of Succession: Succession is of two main types, Primary and Secondary

1. **Primary Succession or Prisere:** It is succession that takes place on a biologically sterile soilless primary substratum or primary barren area.

   Examples of areas where primary succession occurs are newly cooled lava, bare rock, newly created pond or reservoir. The establishment of a new biotic community is generally slow. Before a biotic community of diverse organisms can become established, there must be soil. Depending mostly on the climate, it takes natural processes several hundred to several thousand years to produce fertile soil on bare rock.
2. **Secondary Succession or Subsere:** It is ecological succession that takes place in a recently denuded area which still contains a lot of organic matter. Secondary Succession is more common. Secondary succession begins in areas where natural biotic communities have been destroyed such as in abandoned farm lands, burned or cut forests, lands that have been flooded. Since some soil or sediment is present, succession is faster than primary succession.

Succession of Plants

Based on the nature of the habitat – whether it is water (or very wet areas) or it is on very dry areas – succession of plants is called hydrarch or xerarch, respectively. **Hydrarch succession** takes place in wetter areas and the successional series progress from hydric to the mesic conditions. As against this, **xerarch succession** takes place in dry areas and the series progress from xeric to mesic conditions. Hence, both hydrarch and xerarch successions lead to medium water conditions (mesic) – neither too dry (xeric) nor too wet (hydric).

Hydrarch: It is biotic succession that occurs in aquatic environment like newly formed lake or pond. The various stages in hydrarch are as follows:

1. **Plankton stage:** It is the pioneer community that develops over the surface of newly formed water body. It includes phytoplanktons and zooplanktons.
2. **Submerged stage:** It develops where water is 3-6 metres in depth. The common plants belonging to submerged stage are *Hydrilla, Potamogeton* etc.
3. **Floating Leaved Anchored Stage:** It develops where water depth is 1-3 metres. Common examples are *Nymphaea, Nelumbo* etc.
4. **Floating Stage:** Enrichment of water with nutrients invites fast growing free floating plants. Examples are *Lemna, Azolla, and Salvinia* etc.
5. **Reed Swamp stage:** It develops on shallow banks where depth of water is 0.3-1.0 m. For example, *Typha, Saggittaria* etc.
6. **Marsh Meadow or Sedge Stage:** The stage develops on newly built shore which may get inundated during rains. Common examples are *Cyperus, Juncus, and Carex* etc.
7. **Woodland Stage:** It consists of shrubs and small trees which can tolerate bright sunlight. Example, *Salix, Populus* etc.
8. **Forest Stage:** Slowly, the woodland is replaced by forest.

Xerosere or Xerarch:

This type of succession begins in dry area such as bare rock surface where there is severe scarcity of water and nutrient deficiency. The original substratum is deficient in organic matter. The minerals are present in disintegrated unweathered state. The different stages are as follows:

i. **Pioneer or crustose lichen stage:** The first species on the bare ground is pioneer plant species. These are often 'opportunist' who rapidly exploits the resources when enter into new area and grow best in the absence of competition for space and resources (figure 8). The bare ground is dry and hard with full exposure to sunlight and rapidly changing moisture conditions. In the absence of soil, the root penetration is not possible and supply of nutrients is also very less. Under these conditions, pioneer species of lichens such as *Rinodena, Rhizocarpon, Lecanora and Licidea* are found which are brought there in the form of spore or by fragmentation by wind. These Lichens produces acids which accelerates the process of weathering and when they die, their dead organic matter mixed with rocks to form thin layer of soil. They are replaced by foliose type of lichens.

ii. **Foliose lichen stage:** The foliose lichen stage appears on the substratum which is built up by previous existing crustose lichens. These foliose lichens include *Parmelia, Dermatocarpon, and Umbilicaria*. The thallus of these lichens shadow the previous crustose lichens and gradually the crustose lichen die and decay. These species are able to absorb large amount of water and accumulate dust particles. The water and humus are continuously accumulated in the area and evaporation process is decreased.

iii. **Moss stage:** Accumulation of sufficient amount of soil allows the growth of xerophytic mosses like *Grimmia* (black moss), *Tortula* (twisted moss) and Polytrichum (Hair moss). The rhizoids of these mosses compete with lichens for nutrients and other resources and their erect stem overshadows the earlier established communities (foliage lichens). The death of mosses further increase the amount of soil and a thick mat of dead moss is formed over the rocks, which can absorb the large amount of water. This change in the structure and quality of soil allows the invasion of new communities of herbs. As a result of low growth and carpeting over ground with little height, many mosses are unable to compete for space amongst taller, dense ground cover. This makes bare ground for the establishment of different moss species. These mosses provide suitable microhabitat for a variety of invertebrates like as mites and spiders.

iv. **Herbaceous stage:** Death and decay of mosses make the ground more fertile and make thick cushiony carpets with more water-holding capacity. These new conditions of the environment make suitable place for the germination and establishment of seeds of other competing plants. The soil is now suitable for the germination and growth of seeds of xerophytic herbs. The first established herbs appeared on the ground are annuals and later biennial and perennial grasses appeared. These herbs finally grow into tall, dark thickets which overshadow and displace the moss. Due to death and decay of grassy plants such as *Poa* and *Festuca*, further humus increase in the humus takes place. Temperature and evaporation process declined and result in shortened drought period. These changed conditions favoured the growth of shrubs.

v. **Shrub stage:** As the conditions become favourable for shrubs, seeds or invaders from the adjacent area reach and establish in the area and make the conditions unsuitable for the herbs. Shade of shrubs minimizes evaporation, increases humidity and wind movement is retarded. These modified environmental conditions with enriched soil provide ideal conditions for the growth of tree seedlings. Not only plants, invertebrates that feed on plant species also colonize the area. The presence of herbivores also attracts various carnivorous invertebrates which feed on them. A number of small mammals also appear in the area including shrews and mice which in turn attract carnivores (owls and foxes) to feed on them. The various interactions of different communities are established in the area. The earlier simple food chains of pioneer stage transforms into more complex food webs.

vi. **Climax forest stage**: The first species of the trees which established in the area are relatively xeric having stunted growth and distributed widely. Process of soil formation continues and moisture in soil increases gradually. Humus concentration further increases due to death and decaying of plant species which increase the fertility of soil. As a result, number of tree species further increase in the area. The xeric species is replaced by mesophytic species and give rise to new vegetation indicating a more humid atmosphere. Finally the succession stage reaches into forest which is self-sustainable and interacts with environment. This stage is called as climax community in which rich fauna develops in the area having several species of invertebrates and vertebrates. These include arthropods, mollusks, amphibians, birds, reptiles, small rodents and mammals (like fox etc).

Characteristics of Plant Communities

Generally, analysis of community characters is being done for two specific purposes:

i. To record variation within and between communities and

ii. For naming and classifying communities.

Analytical characteristics are those features of community which can be observed or measured directly in each aspect. It involves measurements of various characters in sample plots, commonly known as quadrats. Measurements made in sample plots (quadrats) are scientifically processed to reflect the characteristics of the entire community.

Two sets of characters, viz.:

i. Analytical, and

ii. Synthetic

1. **Analytic Characters:**

They are directly observed or measured in sample plots. They include kinds and number of species, distribution of individuals, number of individuals, height of plants, etc.

2. **Synthetic Characters:**

They are derived from the measurements of analytic characters and utilise data obtained in the analysis of a number of stands.

1. **Analytical characters are of two types:**

(i) Qualitative:

They are based on non-quantitative observations, e.g., species composition and stratification of vegetation. They are expressed only in qualitative way. **(ii) Quantitative:** They are expressed in quantitative terms. They are measured. The major quantitative characters include frequency, diversity, cover, biomass, leaf size, abundance, dominance, etc.

They are as follows:

Frequency:

This is based on percentage of sample plots in which a species is present, indicating its dispersion in space.

This frequency of each species is calculated as follows:

Frequency percentage = number of sampling units in which that species occurred / number of sampling units studied X 100

Diversity:

This is denoted by number of individuals per unit area, indicating the relative abundance of a species.

Cover and Basal Area:

This is percentage land area occupied by a species, indicating the influence zone of a species. Although sometimes used in general sense for the area occupied by a plant, (which may be the herbage cover or the cover of basal area), it is generally used for above ground parts.

Thus, cover or herbage cover signifies primarily the area of the ground occupied by the above ground parts of plants, such as leaves, stems and inflorescences as viewed from above.

However, basal area refers to the ground actually penetrated by the stems and is readily seen when the leaves and stems are clipped at the ground surface. It is one of the chief characteristics to determine dominance. It is measured either at 2.5 cm above ground or actually on the ground level.

Biomass:

This expresses quantity of living materials per unit area, indicating the growth of a species. Thus, biomass is the standing crop expressed in terms of weight (i.e., organism mass) of the living matter present. The amount of living material, present in a component population at any time, is known as the standing crop, which may be expressed in terms of weight per unit area.

Leaf Area:

The percentages of species having different leaf sizes, indicating the adaptation of the vegetation to the prevailing environment. As the leaves are essential part and are very much affected by climate condition, their shapes and sizes have been taken as important criteria in determination of quantitative characters.

Density:

Density represents the numerical strength of a species in the community. The number of individuals of that species in any unit area is its density. This gives an idea of degree of competition.

It is calculated as follows:

Density = Number of individuals of the species in all the sampling unit/Total number of sampling units studied

The value thus obtained is then expressed as number of individuals per unit area.

Abundance:

This is the number of individuals of any species per sampling unit of occurrence.

It is calculated as follows:

Abundance =Total number of individuals of the species in all the sampling units/Number of sampling units studied

Synthetic Characters:

These are determined after computing the data on the quantitative and quantitative characters of the community. For comparing the vegetation of different areas, community comparison needs the calculation of their synthetic characters. These are determined in terms of presence and Constance, fidelity, etc.

Presence and Constance:

It expresses the extent of occurrence of the individuals of a particular species in the community.

Fidelity:

This is the degree with which a species is restricted in distribution to one kind of community. Such species are sometimes known as indicators.

Dominance:

Here, the dominance is expressed in synthetic form. On the basis of density, frequency and dominance (cover) values; there has been proposed idea of Importance Value Index (IVI). IVI of a species in the community give the idea of its relative importance. For IVI, values of Relative density.

Relative frequency and Relative dominance (cover basis) are obtained as follows:

Relative density = Density of the species x 100/Total density of all the species

Relative Frequency = Frequency of the species x 100/Total frequency of all the species

Relative dominance (cover) = Dominance (cover) of the species x 100/Total dominance (cover) of all the species

Now for IVI, three values are added. IVI values of different species are then arranged in decreasing order.

Other Synthetic Characters:

In addition to above mentioned characters, there are some other synthetic characters. They are quite useful in comparative studies on communities. Such characters include, interspecific association and association index, index of similarity, dominance index, species diversity and diversity index, etc.

Biogeographic regions of India

India is the seventh largest country in the world and Asia's second largest nation with an area of 3,287,263 sq.km. encompassing a varied landscape rich in natural resources. India is shielded by the world's highest mountains, the Himalayas, in the north. The southern part of India takes the shape of a peninsula and divides the Indian Ocean into the Bay of Bengal to the southeast and the Arabian Sea to the southwest. The southern tip of Kanyakumari is washed by the Indian Ocean. The Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep group of islands in the Arabian sea are also a part of India.

India has a great diversity of natural ecosystems from the cold and high Himalayan ranges to the sea coasts, from the wet northeastern green forests to the dry northwestern arid deserts, different types of forests, wetlands, islands and the oceans. India consists of fertile river plains and high plateaus and several major rivers, including the Ganges, Brahmaputra and Indus. The climate of India is determined by the southwest monsoon between June and October, the northeast monsoon between October and November and dry winds from the north between December and February. From March to May the climate is dry and hot.

The country has 10 different biogeographic zones and 26 biotic provinces.

1. **THE TRANS-HIMALAYAN REGION**

   This area is very cold and arid. The only vegetation is a sparse alpine steppe. Extensive areas consist of bare rock and glaciers.

   The faunal groups best represented here are wild sheep and goats (chief ancestral stock), ibex, snow leopard, marbled cat, marmots and black-necked crane.

2. **THE HIMALAYAN REGION**

   The fantastic altitude gradient results in the tremendous biodiversity of the Himalayan region. Flora and fauna vary according to both altitude and climatic conditions: tropical rainforests in the Eastern Himalayas and dense subtropical and alpine forests in the Central and Western Himalayas. The lower levels of the mountain range support many types of orchids. On the eastern slopes, rhododendrons grow to tree height.

Animals of Himalayas show several behavioural and physiological adaptations. Sambar and muntjac are found in the subtropical foothills; serow, goral and the Himalayan thar are found in the temperate and subalpine regions; snow leopard and brown bear inhabit the alpine region. Carnivores are the most elusive of all mammals in the Himalayas. There are a variety of carnivores in the higher mountains, some of which are rare and threatened with extinction.

3. THE INDIAN DESERT

The natural vegetation consists of tropical thorn forests and tropical dry deciduous forests, sandy deserts with seasonal salt marshes and mangroves are found in the main estuaries. Typical shrubs are phog growing on sand dunes. Sewan grass covers extensive areas called pali.

Thar desert possesses most of the major insect species. 43 reptile species and moderate bird endemism are found here. No niche of the Thar is devoid of birds. The black buck was once the dominant mammal of the desert region, now confined only to certain pockets. The gazelle is the only species of the Indian antelope of which the females have horns. Nilgai the largest antelope of India and the wild ass, a distinct subspecies, is now confined to the Rann of Kutch which is also the only breeding site in the Indian subcontinent for the flamingoes. Other species like desert fox, great Indian bustard, and chinkara and desert cat are also found.

4. THE SEMI-ARID REGION

The semi-arid region in the west of India includes the arid desert areas of Thar and Rajasthan extending to the Gulf of Kutch and Cambay and the whole Kathiawar peninsula.

The natural vegetation consists of tropical thorn forests and tropical dry deciduous forests, moisture forests (extreme north) and mangroves. The sandy plains have a few scattered trees of *Acacia* and *Prosopis*. The gravelly plains have *Calotropis, Gymnosporia*, etc. The rocky habitats are covered by bushes of Euphorbia while species of *Salvadora* and *Tamarix* occur mainly near saline depressions. The lion of Gir is the endemic species in this zone.

5. THE WESTERN GHATS

They cover only 5% of India's land surface but are home to more than about 4,000 of the country's plant species of which 1800 are endemic. The monsoon forests occur both on the western margins of the ghats and on the eastern side where there is less rainfall. This zone displays diversity of forests from evergreen to dry deciduous.

The Nilgiri langur, lion tailed macaque, Nilgiri tahr, Malabar grey hornbill and Most amphibian species are endemic to the Western Ghats.

6. THE DECCAN PENINSULA

The Deccan Peninsula is a large area of raised land covering about 43% of India's total land surface. It is bound by the Sathpura range on the north, Western Ghats on the west and Eastern Ghats on the east. The elevation of the plateau varies from 900 mts. in the west to 300 mts. in the east. There are four major rivers that support the wetlands of this region which have fertile black and red soil. Large parts are covered by tropical forests. Tropical dry deciduous forests occur in the northern, central and southern part of the plateau. The eastern part of the plateau in Andhra Pradesh, Madhya Pradesh and Orissa has moist deciduous forests.

Fauna like tiger, sloth bear, wild boar, gaur, sambar and chital are found throughout the zone along with small relict populations of wild buffaloes, elephants and barasingha.

7. THE GANGETIC PLAIN

The Gangetic plain is one of India's most fertile regions. The soil of this region is formed by the alluvial deposits of the Ganges and its tributaries. The four important surface differences recognized in the geomorphology of the plains are

Bhabar - pebble studded zone with porous beds

Terai - marshy tract

Bhangar - older alluvium of the flood plain

Terai - marshy tract

Khadar -newer alluviumThe Gangetic plains stretching from eastern

Rajasthan through Uttar Pradesh to Bihar and West Bengal are mostly under agriculture. The large forest area is under tropical dry deciduous forest and the southeastern end of the Gangetic plain merges with the littoral and mangroves regions of the Sunderbans.

The fauna includes elephants, black buck, gazelle, rhinoceros, Bengal florican, crocodile, freshwater turtle and a dense waterfowl community.

8. THE COASTAL REGION

The natural vegetation consists of mangroves. Animal species include dugong, dolphins, crocodiles and avifauna. There are 26 species of fresh water turtles and tortoises in India and 5 species of marine turtles, which inhabit and feed in coastal waters and lay their eggs on suitable beaches. Tortoise live and breed mainly on the land.

Over 200,000 Olive Ridley turtles come to Orissa to nest in the space of three or four nights. The highest tiger population is found in the Sunderbans along the east coast adjoining the Bay of Bengal.

Lakshadweep consists of 36 major islands - 12 atolls, 3 reefs and 5 submerged coral banks - make up this group of islands more than three hundred kilometers to the west of the Kerala coast. The geographical area is 32 sq. km. and the usable land area is 26.32 sq. km. The fauna consists mainly of four species of turtles, 36 species of crabs, 12 bivalves, 41 species of sponges including typical coral, ornamental fishes and dugongs. A total of 104 scleractinian corals belonging to 37 genera are reported.

9: THE NORTH-EAST

Biological resources are rich in this zone. The tropical vegetation of northeast India is rich in evergreen and semievergreen rain forests, moist deciduous monsoon forests, swamps and grasslands.

Mammalian fauna includes 390 species of which 63% are found in Assam. The area is rich in smaller carnivores. The country's highest population of elephants are found here

10. THE INDIAN ISLANDS

It is a group of 325 islands: Andaman to the north and Nicobar to the south. The two are separated by about 160 kms. by the Ten Degree Channel of the sea. The rainfall is heavy, with both Northeast and Southwest monsoons. At present, 21 of the 325 islands in the Andaman & Nicobar Islands are inhabited. Many unique plants and animals are found here. About 2,200 species of higher plants are found here of which 200 are endemic. The Andaman & Nicobar Islands have tropical evergreen forests and tropical semievergreen forests as well as moist deciduous forests, littoral and mangrove forests. 112 endemic species of avifauna, the Andaman water monitor, giant robber crab, 4 species of turtles, wild boar, Andaman day gecko and the harmless Andaman water snake are found only in these islands. The Narcondam hornbill found only in Narcondam is a large forest bird with a big beak. Coral reefs are stretched over an area of 11,000 sq.km. in the Andamans and 2,700 sq.km. in Nicobar.

CAUSES OF ECOLOGICAL DESTRUCTION AND DEPLETION

The rapid deterioration of the ecology due to human interference is aiding the disappearance of wildlife from the biosphere. The common problems a habitat disturbance and destruction, introduction of exotics, exploitation, marine pollution, natural disasters like floods, earthquakes and forest fires.

The major problems of certain specific zones are as follows.

- **Wetlands**: siltation, eutrophication, encroachment, tourism.
- **Forests**: deforestation and degradation, extended cultivation, road laying, mining operation.
- **Seas**: hot water from nuclear and thermal power plants, toxic

effluents from coastal areas, oil spills, blasting and dredging, collection of undersized fishes and other organisms, exploitation of ornamental seashells, chanks and pearl oysters by domestic shell craft industry, export of sea fans and seaweeds.

- **Corals**: used as a raw material in the cement factories, exploitation of antipatharians and precious red coral for jewellery, commercial exploitation of aquarium fishes from Indian coral reefs.
- **Mangroves**: agriculture, aquaculture, fuel wood extraction, diversion of fresh water for irrigation resulting in increased salinity.
- **Rivers**: heavy metal pollution, persistent biocides, organic wastes, removal of sand from river beds.
- **Animals**: exploited for their skin, fur, wood, tusk, meat, medicine and oil, trade, hunting, poaching.

LEGISLATION FOR PROTECTING ENDANGERED SPECIES

- Considering the importance of flora and fauna, major national and international efforts have been make to protect and conserve the rich biodiversity and endangered species of wildlife and flora. Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES), 1973, is a significant step in this direction. The convention recognized that wild fauna and flora in their many beautiful and varied forms are irreplaceable parts of the natural systems of the earth, which must be protected by all means. The United Nations Convention on Biological Diversity, 1992 is another milestone.
- The Wildlife (Protection) Act, 1972, is our national initiative to protect wildlife. The Act provides for establishment of a Wildlife Board and setting up of Wildlife Sanctuaries and National Parks. The Act also makes hunting of wild animals a punishable offence. The Biological Diversity Bill, 2000 which is in the offing, also interalia, strives to protect and conserve the biodiversity and endangered species in India.

ECOSYSTEM BALANCE

There is an urgent need for sustaining wild species due to the following reasons.

- Forests render the climate more equable, prevent soil erosion and landslides and help in flood control
- Most of today's food crops were domesticated from wild tropical plant
- About 80% of the world's population relies on plants or plant extracts for medicines
- Pollination and seed dispersal by birds, insects and animals is essential to increase diversity of genetic recombination
- Agricultural scientists and genetic engineers require the existing total stock of species - most of them still unknown and unnamed - as the source of food and to develop the new crop strains of tomorrow
- Survival of humans and other species is dependent on the producer
- Wildlife serves as a gene library; premature extinction of species leads to irreversible loss of genetic information that influences the future evolution of life on earth Aesthetic value

Biodiversity and ecological integrity are essential to all life on earth and should not be disturbed by human actions. To save the natural world, ecosystems as a whole have to be saved. Unless the entire ecosystem is preserved, the individual species will not be able to survive for long. The steps taken to preserve our wildlife are:

- Gene banks and Botanical Gardens
- Zoological Gardens and Captive Breeding Centres
- Biosphere Reserves
- National Parks and Wildlife Sanctuaries
- Treaties and laws to protect endangered species

The water cycle

Key points

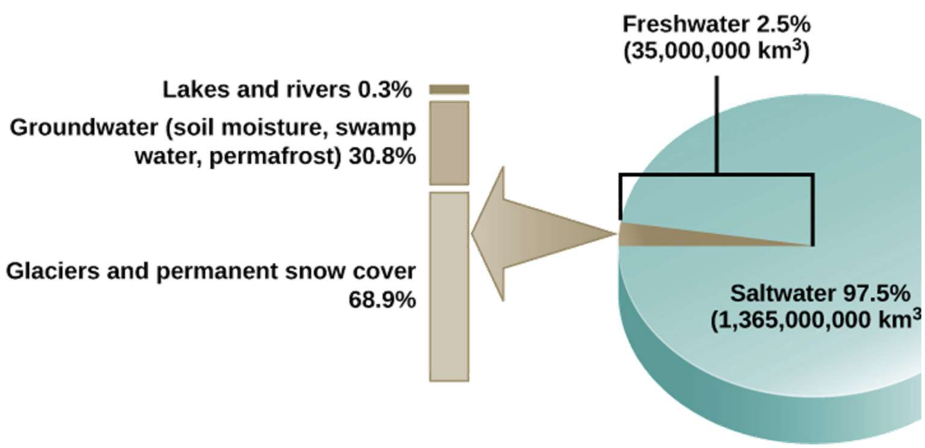
- The vast majority of Earth's water is saltwater found in oceans. Only a tiny fraction is readily accessible freshwater, which is what humans need.

- Water found at the Earth's surface can cycle rapidly, but much of Earth's water lies in ice, oceans, and underground reservoirs; this water cycles slowly.
- The water cycle is complex and involves state changes in water as well as the physical movement of water through and between ecosystems.
- **Groundwater** is found underground between soil particles and in cracks of rocks. **Aquifers** are groundwater reservoirs often tapped by wells.

Water: Why does it matter?

Water is pretty darn important for living things. Your body is more than one-half water, and if we were to take a look at your cells, we'd find they were over 70% water! So, you—like most land animals—need a reliable supply of fresh water to survive.

Of the water on Earth, 97.5% is salt water. Of the remaining water, over 99% is in the form of underground water or ice. All told, less than 1% of fresh water is found in lakes, rivers, and other available surface forms.



Many living things depend on this small supply of surface fresh water, and lack of water can have serious effects on ecosystems. Humans, of course, have come up with some technologies to increase water availability. These include digging wells to get at groundwater, collecting rainwater, and using desalination—salt removal—to get fresh water from the ocean. Still, clean, safe drinking water is not always available in many parts of the world today.

Most of the water on Earth does not cycle—move from one place to another—very rapidly. We can see this in the figure below, which shows the average time that an individual water molecule spends in each of Earth's major water reservoirs, a measurement called **residence time**. Water in oceans, underground, and in the form of ice tends to cycle very slowly. Only surface water cycles rapidly.

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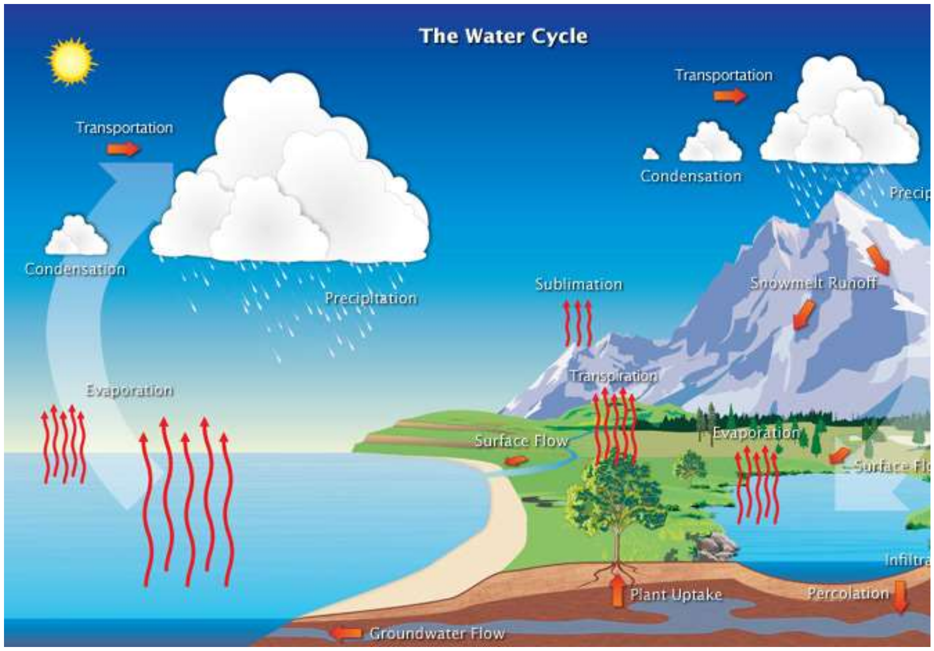
The water cycle

The water cycle is driven by the Sun's energy. The sun warms the ocean surface and other surface water, causing liquid water to evaporate and ice to sublime—turn directly from a solid to a gas. These sun-driven processes move water into the atmosphere in the form of water vapor.

Over time, water vapor in the atmosphere condenses into clouds and eventually falls as **precipitation**, rain or snow. When precipitation reaches Earth's surface, it has a few options: it may evaporate again, flow over the surface, or **percolate**—sink down—into the ground.

In land-based, or **terrestrial**, ecosystems in their natural state, rain usually hits the leaves and other surfaces of plants before it reaches the soil. Some water evaporates quickly from the surfaces of the plants. The water that's left reaches the soil and, in most cases, will begin to move down into it.

In general, water moves along the surface as **runoff** only when the soil is saturated with water, when rain is falling very hard, or when the surface can't absorb much water. A non-absorbent surface could be rock in a natural ecosystem or asphalt or cement in an urban or suburban ecosystem.



Water in the upper levels of the soil can be taken up by plant roots. Plants use some of the water for their own metabolism, and water that's in plant tissues can find its way into animals' bodies when the plants get eaten. However, most of the water that enters a plant's body will be lost back to the atmosphere in a process called **transpiration**. In transpiration, water enters through the roots, travels upwards through vascular tubes made out of dead cells, and evaporates through pores called stomata found in the leaves.

If water is not taken up by plant roots, it may percolate down into the subsoil and bedrock, forming groundwater. **Groundwater** is water found in the pores between particles in sand and gravel or in the cracks in rocks, and it's an important reservoir of freshwater. Shallow groundwater flows slowly through pores and fissures and may eventually find its way to a stream or lake, where it can become part of the surface water again.

Some groundwater lies deep in the bedrock and can stay there for millennia. Groundwater reservoirs, or *aquifers*, are usually the source of drinking or irrigation water drawn up through wells. Today, many aquifers are being used up faster than they're renewed by water that moves down from above.

The water cycle drives other cycles.

The water cycle is important in itself, and patterns of water cycling and rainfall have major effects on Earth's ecosystems. However, rainfall and surface runoff also play important roles in the cycling of various elements. These include carbon, nitrogen, phosphorus, and sulfur. In particular, surface runoff helps move elements from terrestrial, land-based, to aquatic ecosystems.

Remote Sensing

Remote Sensing is defined as- — the science and art of acquiring information (spectral, spatial, and temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. In recent years, remote sensing technology has proved to be of great importance in acquiring data for effective resources management and can be applied to coastal environment monitoring and management (Ramachandran, 1993; Ramachandran et.al., 1997). Recent advancement in RS technology is of great importance in acquiring data in more efficient way which is beneficial in quick change detection and effective resource management. Remote sensing technology may be divided into three phases:

(i) Data collection from a sensor mounted on a platform e.g. a satellite;

(ii) (ii) Data handling;

(iii) (iii) Data interpretation which end up in producing some thematic maps of the investigated surfaces. Data acquired by RS is interpreted with the help of GIS software‘s.

Geographical Information System

A Geographical Information System is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modelling, representation, display of geographical data to solve complex problems regarding planning and management of resources. Functions of GIS include data entry, display, management, information retrieval and analysis. A geographic information system captures, stores, analyses, manages and presents data, which is linked to locations or having spatial distribution. Any

GIS application and/or operation contain five essential elements: data acquisition; pre-processing; data management; manipulation and analysis; and product generation (Star and Estes, 1990; Antenucci, et al., 1991 & Canter, et al., 1994).

It is a computer-based system that provides four sets of capabilities to handle geo-reference data, such are:

1. Data capture: graphic data include digitization and attribute data
2. Keyed-in loaded from existing data files
3. Data storage and manipulation: file management and editing
4. Data analysis: database query, spatial analysis and modelling
5. Data display: maps and reports

This is quite simply because this type of data calls for the utilisation of GIS capabilities and when one considers that GIS is becoming simpler to use and much cheaper to buy, it is hard to imagine a future for environmental monitoring systems without it (Schroeter and Olsen, 1996). A GIS can manage different data types occupying the same geographic space. The GIS software for database management provides users with the means to define the contents of a database, insert new data, delete old data, identify database contents and modify the contents of the database (Star and Estes, 1990). The major advantage of GIS is that it can read and analyze different layers of spatial information in the form of maps and satellite images easily and allows identifying the spatial relationships. Thus, it is software used for storing, retrieving and presenting both spatial and non-spatial data in an efficient, quick, and structured way. Geographical Information System (GIS) is composition of traditional sciences, contemporary science and technology. GIS is a tool for management, manipulation, analysis, modelling, representation of geographical information recorded with the help of RS. Data entry, data display, data management, information retrieval, and analysis are the functions of GIS. In GIS software‘s geo-referenced data is analyzed in four steps captures, stores, analyses, manages, and presents data, which is linked to locations or having spatial distribution . It is a computer-based system that provides four sets of competence to handle geo-reference data like data capture (digitized, converted from existing data),

data storage and manipulation, data analysis (database query, spatial analysis and modelling), and data display (maps and reports).

Data acquisition refers to the process of identifying and collecting the data required for the application. After data acquisition, the methods used to covert a dataset into a suitable format for input into the GIS is known as pre-processing. Data format conversion, such as digitization of maps and printed records and recording this data into a computer database, is the key step in pre-processing. Pre-processing also contains map projection, data reduction and generalization, error detection, and interpolation. Generally, data sets are manipulated before and after entering into the computer in such a way that they are mentioned to a common geodetic coordinate (e.g. Universal Transverse Mercator (UTM)), orientation and scale. There are many GIS software‘s as per your needs e.g; ERDAS, ArcView, ArcGIS, SWAT, which allow developers to add dynamic mapping, improves image quality, overlapping etc (Ormsby et al., 2010). The datasets can be manipulated as needed by the analysis. Some of the operations used in data manipulation are analogous to those used in pre-processing. Many types of analyses are feasible within a GIS; among these are mathematical combinations of layers, Boolean operations and, with external programs using the GIS as a database, complex simulations. Final output of GIS is fully classified map or image which is easy to understand and pass minimum noise.

Advantages of GIS

On the basis of GIS, the digital data base has been developed stage can also be used in future and any related information can be extracted conveniently and efficiently. New information overlaps can also be maps with newly defined user condition. The other advantages of using GIS for resources investigation can be summarized as follows:

A: GIS is a powerful tool for handling data collected from a variety of sources at different scales and resolution.

B: Large quantities of data can be stored, maintained and retrieved with a greater speed and low cost.

C: GIS is able to manipulate and integrate different types of data in a single analysis, which is an impossible task.

D: It can perform complex spatial analysis providing both qualitative and quantitative results.

E: GIS is extremely helpful in planning scenarios, decision models and interactive processes.

F: Remotely sensed data used for resource mapping, monitoring and management.

Remote Sensing and Geographical Information System in EIA

Geographical Information System (GIS) is a computer based system which can be used to store, integrate, analyze, and display spatial and non spatial data for undertaking an EIA study. The first GIS system was evolved in the late sixties, and by mid seventies, it was used for EIA. Overlay technique method is one of the main methods of analysis in GIS. In 1972, a computerized version of the GIS technique was used for setting power lines and roads (Munn, 1975). First GIS (Canada GIS or CGIS) was used for EIA in the late 1970s for the preparation of an EIS for a dam on the river Thames. GIS processes are related to environment for considering the spatial properties of the housing projects. Most of the environmental issues can be handled properly with the use of GIS techniques (Schaller, 1990). Due to the evolution of computer technology, and their graphic capabilities, GIS's have become more users friendly and powerful. The availability and quality of digital spatial data sets have improved for routine analysis (Batty, 1993).

GIS is widely utilized in EIA of housing projects, however, its use is largely limited to the fundamental GIS functions such as map production, classic overlay or buffering (Joao, 1998). The use of GIS in EIA process is common for scoping in terms of time and money relative to the time and budgets allocated for EIA preparation, and especially for scoping studies. The key advantage of GIS for EIA is its ability to perform spatial analysis and modelling (Joao and Fonseca, 1996) for future urban growth projections in world‘s developing and upcoming urban townships.

There are several advantages of Remote Sensing and Geographical Information System techniques in EIA which are outlined below:

1. Space management which is a major issue concerning the provision of limited space to meet housing goals, minimize operating costs and promote an effective and productive environment. The ideal uses of space in successful manner decreases the building‘s per capita functional costs. There are several cases where GIS is effectively used in the management of spaces for different housing projects.

2. The suitable site selection is the primary and essential part of eco-city/housing projects planning. GIS can be utilized to visualize whether a particular site meets the predefined criterions or not. It helps to visualize the spatial interlinks or errors between various factors with that of chosen site for planning. GIS techniques help to generate several important functional maps for the master plan such as the location of the waste management sites, green space, parks and open areas etc.

3. Housing and construction industry is one of the major sources for Green House Gas (GHG) emission. Reducing the GHG emission from the construction activities is one of the critical challenging issues in construction industry. So, GIS technique helps in monitoring GHG emission from the construction activities. The maps generated from several sources could be overlaid to prepare the emission scenario and its impact on settlements (Denga et al., 2008).

4. Many applications are enhanced by the use of 3-D spatial information, such as visualization of planning development proposals, flood predictions, modelling urban sprawl, tourist visit simulations and the design of transportation networks. Some GIS software also predicts the future growth with the help of modelling techniques.

Ethnobotany: An Introduction

People of all cultures have always depended on plants for their primary needs (food, shelter, warmth, medicines, etc.), and have naturally learned diverse applications of plants. In the course of nomadic roaming, this knowledge was exchanged with neighboring tribes, friends and foe, and was gradually expanded upon. Thus, plant knowledge has been passed around the world since the beginning of time, and frequently, the actual plants themselves have spread along as well. The investigation of plants and their uses is one of the most primary human concerns and has been practiced by all cultures since generations, though it wasn't called '**Ethnobotany**'. The term "Ethnobotany" was coined by US botanist John William Harshberger in 1895. Ethnobotany is coined with two terms i.e., "ethno" - study of people and "botany" - study of plants; per se it is the study of the relationship between plants and people. It is considered as a branch of ethnobiology and is a multidisciplinary science defined as the interaction between plants and people. The relationship between plants and human cultures is not limited to the use of plants for food, clothing and shelter but also includes their use for religious ceremonies, ornamentation and health care (Schultes, 1992). The focus of ethnobotany is on how plants have been or are used, managed and perceived in human societies and includes plants used for food, medicine, divination, cosmetics, dyeing, textiles, for building, tools, currency, clothing, rituals, social life and music. The relationship between people and plants has always been profoundly important. Plants play an important role in every aspect of our lives and without them life is not possible. Plants not only regulate the concentration of gases in the air, but also the only organisms capable of transforming sunlight into food energy on which all other forms of life ultimately depend upon. Given their extensive range of knowledge of medicinal plants, indigenous people remain the ultimate resource for retrieving this information for the purpose of application, particularly in modern medicine. Ethnobotany can be categorized in two major groups. First is basic ethnobotany that includes compilation and organization of information about biota obtained from indigenous and other peoples, such as obtaining data about useful plants and animals, understanding how peoples manage their environments and learning about their lexicons and classifications. This is what we try to do in the best possible way, directly in the field from original sources. These results can then be organized in many ways once species determinations are completed. They may Basic quantitative and experimental ethnobotany includes basic documentation, quantitative evaluation of use and management and experimental assessment.

In the past, ethnobotanical research was predominately a survey of the plants used by villagers. A trained botanist identified the plants and recorded their uses. Sometimes an anthropologist was present to translate the disease descriptions, but rarely was a physician available to identify the disease. The results generated a list of plants and their uses which was published in a professional journal, usually in the country of the scientist. Nothing was communicated or returned to the cultural group in exchange for their participation in the survey, nor was any environmental or cultural status or concerns included in the survey. Today, ethnobotanical surveys include applied projects that have the potential to ameliorate poverty levels of these people, allowing them to make more educated decisions about their future directions. These new approaches enhance the quality of the science, provide compensation for the cultural groups and take into account environmental concerns. This modern approach is based on an interdisciplinary team usually composed of an ethnobotanist, an anthropologist, an ecologist and a physician. Some of these team members are remote area colleagues who have arranged the details of the expedition as well as the contractual agreements for reciprocal programs of the village or community.

Ethnobotany and Traditional Medicine System

The Indian subcontinent, with the history of one of the oldest civilization, harbors many traditional health care systems. Besides Ayurveda, other traditional and folklore systems of health care were developed in the different time periods in the subcontinent, where more than 7500 plant species were used. According to a WHO estimate, about 80% of the world population relies on traditional systems of medicines for primary health care, where plants form the dominant component over other natural resources. The forests have been the source of invaluable medicinal plants since the time man realized the preventive and curative properties of plants and started using them for human healthcare. Tropical forests are particularly endowed with plants possessing curative properties. These richly biodiverse environments provide a veritable trove of flora containing compounds of medicinal value which indigenous people have utilized and benefited from for centuries. Traditional medicine based on herbal remedies has always played a key role in the health systems of many countries. In India the native people are exploiting a variety of herbals for effective curing of various ailments. The plant parts used, preparation, and administration of drugs vary from one place to other. However, the knowledge of herbal medicines is gradually perishing, although some of the traditional herbal men are still practicing the art of herbal healing effectively. These plants are frequently used by the local inhabitants of the area for treatment of various diseases. The traditional knowledge, skill and practices thus developed are freely exchanged cared for and nourished as a common property of the communities (Pushpangadan, 2005). Investigations into traditional use and management of local flora have demonstrated the existence of extensive local knowledge of not only about the physical and chemical properties of many plant species, but also the phenological and ecological features in the case of domesticated species. Vast ethnobotanical knowledge exists in India from ancient time. Since 1950s the study of ethnobotany has intensified. Much work is now being done on the botany, pharmacognosy, chemistry, pharmacology and biotechnology of herbal drugs. The value of ethnomedicine has been realized; work is being done on psychoactive plants, household remedies and plants sold by street drug vendors. Statistical methods are being used to assess the credibility of claims. Some recent work in drug development relates to species of Commiphora (hypolipidaemic agent), Picrorhiza (hepatoprotective), Bacopa (brain tonic), Curcuma (antiinflammatory) and Asclepias (cardiotonic). A scrutiny of folk claims found 203 plants for evaluation. Less well known ethnomedicines have been identified that are used to treat intestinal, joint, liver and skin diseases.

Ethnobotany Today

Ethnobotany is a rapidly growing science, attracting people with widely varying academic background and interests. It is still predominantly linked to Economic Botany, and thus pursued to determine the potential economic value of various plants. There is a romantic allure to the life of an explorer and the promise of finding 'gold' in the form of plants or animals as potential sources for lifesaving drugs that could become important in the treatment of serious diseases such as AIDS and cancer. Plant ethnomedicinal findings may set the stage for targeting materials which can be meaningfully analysed for chemical activity using appropriate biodirected assays. This approach in search of new pharmaceuticals is woefully underutilized today to the detriment of human health and a number of new strategies should be considered for future advancements in drug discovery. Today the field of ethnobotany requires a variety of skills: botanical training for the identification and preservation of plant specimens; anthropological training to understand the cultural concepts around the perception of plants; linguistic training, at least enough to transcribe local terms and understand native morphology, syntax and semantics. Native healers are often reluctant to accurately share their knowledge to outsiders. In interaction with the traditional areas of science, ethnobotany gives out several interrelated and interdisciplinary subjects involving aspects like, ethnomedicine, ethnoarchaeology, ethnobryology, ethnoecology, ethnoagriculture, ethnonarcotics, ethnopharmacology, etc.

Drug Development

Numerous ethnobotanical studies aimed at identifying new pharmaceutical products have been initiated in recent times. Ethnobotany has played important roles in the development of new drugs for many centuries.

Ethnomedical investigations have led to the development of important drugs such as reserpine (a treatment for hypertension) podophyllotoxin (the base of an important anticancer drug), and vinblastine (used in the treatment of certain cancers). Numerous drugs have entered into the international market through exploration of ethnopharmacology and traditional medicine (Bussmann 2002; Mukherjee and Wahile, 2006) with extensive uses of medicinal plants. It is estimated that 25% of prescription drugs contain active principles derived from higher plants. The advent of highthroughput, mechanism-based in vitro bioassays coupled with candidate plants derived from pain-staking ethnopharmacological research has resulted in the discovery of new pharmaceuticals such as prostratin, a drug candidate for treatment of human immunodeficiency virus, as well as a variety of novel anti-inflammatory compounds. In Africa, drug development based on ethnobotanical leads has followed two paths: the classical approach of identification of single plant species with biologically active compounds and the characterization and standardization of traditional recipes for reformulation as medicines. The first approach has led to the recognition of many African plants as medicines and the isolation of several biologically active molecules; examples range from the well-known physostigmine (from Physostigmu venonosum) used for the treatment of glaucoma to the recently identified antiviral agents from Ancistrocladus abbreviutus. The second approach which aims at optimization of mixed remedies as formulated dosage forms is perhaps more relevant to the needs of the poor rural populations but has remained largely ignored. Drug development programmes based on ethnobotanical leads must provide for just and fair compensation for individual informants and local communities (Iwu, 2002). The value of ethnomedical information in drug development is based on several factors: accuracy in recording or observing the medical use of the ethnomedical preparation, whether or not the ethnomedical use can be corroborated under scientific conditions in the laboratory, the formal or informal experience of the practitioner who provides the information, the role of the placebo effect and perhaps many others. Published ethnomedical information has many strengths and weaknesses relative to the ability to establish a corresponding biological effect in the laboratory. Many of the publications contain insufficient detail for the laboratory scientist. The ability to correlate ethnomedical reports with corresponding scientific studies could lead to improved selection of plants for further study in the areas of arthritis, cancer, diabetes, epilepsy, hypertension, malaria, pain, fungal and viral infections. This combination of analysing ethnomedical information and published scientific studies on plant extracts (ethnopharmacology) may reduce the number of plants that need to be screened for drug discovery attempts, resulting in a corresponding greater success rate than by random selection and mass bioscreening. Despite widespread use of plant resources in traditional medicines, bioassay analysis of very few plant species have been conducted to investigate their medicinal properties, and to ascertain safety and efficacy of traditional remedies. The development of these traditional systems of medicines with the perspectives of safety, efficacy and quality will help not only to preserve this traditional heritage but also to rationalize the use of natural products in the health care. The plant species used by folklore may be explored with the modern scientific approaches for better leads in the health care. The intrinsic importance of these medicinal plants can very well prove as a potential source of new drugs (Mehrotra and Mehrotra, 2005).

Harvesting of Plants The harvesting of plants, meaning removal of plants or their parts for medicinal purposes was considered as most important to healers to ensure long-term availability of the plants. Very often the exploitation of wild harvested resources (medicinal plants) has led to their severe degradation. Documenting the eroding plants and associated indigenous knowledge can be used as a basis for developing management plans for conservation and sustainable use of medicinal plants in the area. The principal threatening factors reported were deforestation, agricultural expansion and overgrazing. Learning of correct methods of harvesting was considered an essential part of local conservation efforts by healers. Most healers of Chhindwara, Madhya Pradesh indicated that no plant part should be removed until the plant is strong enough to withstand the loss. In general, it was felt that a mature plant should be chosen for removal of the required parts. The right method of harvesting varies according to the growth of the plant and nature of the cure. The time at which plant parts are harvested is also important. For instance, many healers, from Chhattisgarh believe that Saturday night is an auspicious time for harvesting. Saturday night harvesting and Sunday treatments are the most common practice among the local healers of Chhattisgarh. In addition, knowledge of special care or practices related to safer harvesting is also considered important. Most of the healers have revealed that their shadow should not fall on the plants while harvesting. Similarly, many healers would never remove the bark in a circular fashion, avoiding a ring shape or complete removal from the stem. They believe that such a removal will permanently damage the xylem cells, which might lead to drying and death of the plants. In addition to these special practices, religious or holy ceremonies are also performed while removing the useful parts of the plants by healers. Many healers from Chhattisgarh offered a handful of rice and prayer to plants before they remove them. During such prayers, they appreciate the effectiveness of the medicinal plants and express their gratitude. Knowledge of planetary movement is also a part of their learning of ceremonial rituals by healers of Satpura region of Madhya Pradesh. "Certain plant parts should only be harvested on a full moon night to get the full vigour of the plant quality in the drug. During full moon nights, other planets in the universe remain calm so that the goddess of plants moves around in forest and showers her blessings". Traditional harvesting practices were taken into consideration while developing sustainable harvesting practices of medicinal plants in Madhya Pradesh and Chhattisgarh. Sustainable harvesting practices of some important medicinal plants have been standardised e.g., Andrographis paniculata (Kalmegh), Rauvolfia serpentina (Sarpagandha), Gymnema sylvestre (Gudmar), Tinospora cordifolia (Giloe), Celastrus paniculatus (Malkangni), Terminalia arjuna (Arjuna), Litsea glutinosa (Maida), Saraca asoka (Ashoka), Holarrhena antidysentrica (Kutaj), Bauhinia veriegata (Kachnar), Embelia tsjerium-cottam (Baividang), Phyllanthus emblica (Aonla). However, there is a need for increased efforts to develop technologies to sustain their extraction. By adopting non-destructive harvesting practices these important valuable resources can be conserved (Pandey, 2009; Pandey and Shackleton, 2012; Pandey and Mandal, 2012). Income from collection and sale of medicinal plants is thought to be marginalized by lack of awareness regarding local and overseas market requirement, local shopkeepers, agents and medicine man. The consumers obtain supplies from individuals who have little experience in medicinal herb preparations or in understanding of its value. As a result valuable economic and medicinal plants are becoming rare and some are at the verge of local extinction. Therefore, efforts should be to conserve these valuable plants for future generations.