ECOLOGY AND ENVIRONMENT MANAGEMENT

BIOMES

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KEYWORDS

Biome, Arctic Tundra, Alpine Tundra, Permafrost, Cryoplanation, Taiga,Coniferous Forest, vertical stratification, Temperate deciduous forest, Temperate evergreen forest, Chapparal, Tropical rainforest, Canopy, Primary productivity, Monsoon forest, Temperate grassland, Savanna, Mulch, Desert Biome, Lentic Ecosystem, Lotic Ecosystem, Euphotic Zone, Aphotic zone, Thermocline, Littoral, Limnetic, Bethic, Eutrophication, Zonation, Plankton, River continuum, Swamp, Marsh, Bog, Peatland, Upwelling, Estuary, Nutrient trap, Mangrove, Coral reef, pelagic, Abyssal, Bathyal, Hadal zone.

BIOMES

Earth has many different combinations of environmental conditions, varying in temperature, moisture, light and other physical factors, that are characteristic of different regions. Each of this region or habitat has distinct life forms living in it, forming complex communities of interdependent organisms. The major regional ecological communities of plants and animals that are well adapted to the physical environment of that region are referred as **biomes.** Each biome is, thus, characterized by a major vegetation type or life form of animals or some other identifying feature of landscape and named accordingly, for instance, tundra biome, grassland biome continental shelf ocean biome, coral reef biome etc.

The world's biomes can be grouped into two broad categories – terrestrial biomes and aquatic biomes.

TERRESTRIAL BIOMES

Terrestrial biomes are differentiated and recognized by predominant life form of climax vegetation. Thus the climax vegetation of grassland biome is grass, although the species vary topographically in different parts of the biomes and on different continents. However, a terrestrial biome is composed not only of the climax vegetation, but also of associated successional communities, persistent sub-climax communities, fauna and soils.

Among the fauna, many mobile animals like birds, mammals, reptiles and many insects move freely between different strata and different successional stages of vegetation, migratory birds even move seasonally between biomes on different continents. Large mammalian herbivores such as deer, caribou, antelope, bison, cattle are a characteristic feature of terrestrial biomes. Many of these herbivores are ruminants, which with the help of the symbiotic micro-organisms living in their rumen, can break down and utilize the lignin and cellulose that constitute the large part of terrestrial plant biomass. Other important features of these biomes are the detrital food chain, which is the major energy flow pathway and the mutualistic association between plant roots and mycorrhizae, nitrogen fixers and other micro-organisms.

The distribution of terrestrial biomes is correlated with the regional climate, especially temperature and precipitation. The interaction of temperature and precipitation determine the kind of vegetation that can develop at a particular site. Whittaker (1975) plotted the boundaries of major vegetation types with respect to average temperature and precipitation in climates between those of forest and desert community types (Figure 3.1). Although this figure does not consider soil type, topography or other important environmental factors that influence biome distribution, still it is a useful general guideline for biome location.

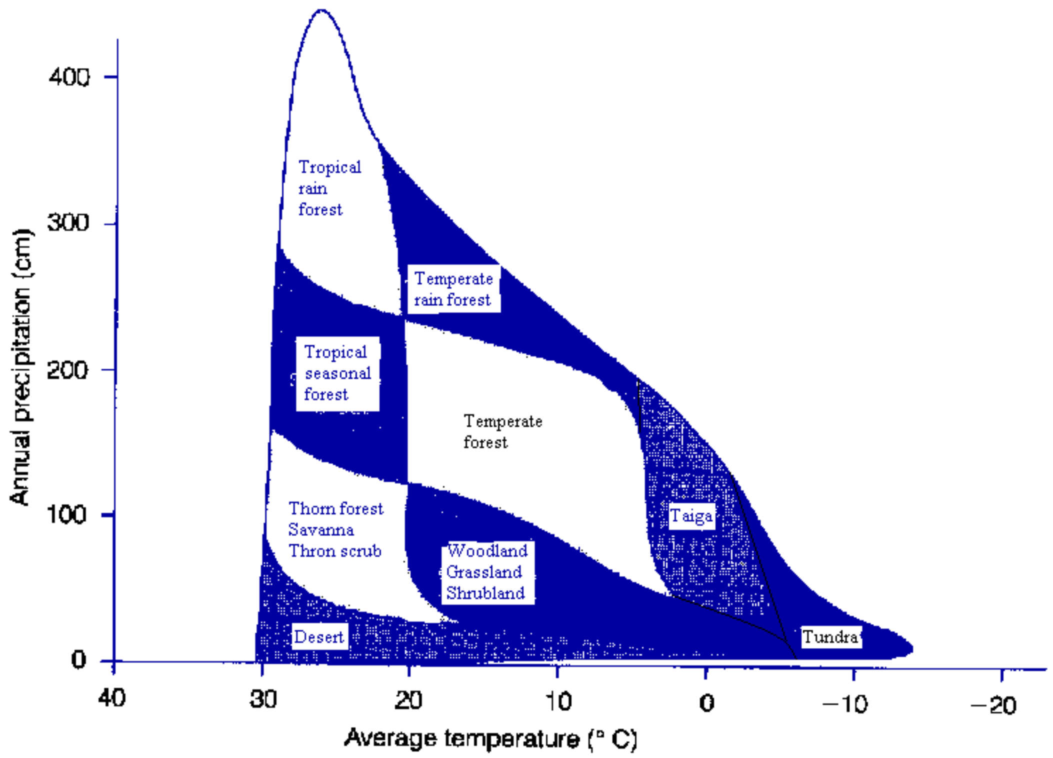


Figure 3.1 - Patterns of world vegetation types based on mean annual temperature and precipitation. (Source: Whittaker, 1975)

TUNDRA BIOME

Tundra is the simplest of all terrestrial biomes in terms of species composition but has harsh environmental conditions like extremely low temperature, low precipitation, poor nutrients and a short growing season. It is a treeless land (the word is derived from the Finnish word *tunturi* meaning treeless plain) that lies in far north between the polar ice caps to the north and forests to the south in the arctic region. Similar regions are also found above the treeline on high mountains at lower latitudes. Thus tundra biome can be divided into two types – arctic tundra (in arctic region) and alpine tundra (at high altitudes on mountains).

Arctic Tundra

Climate, Soil and Topography. Arctic tundra lies north of latitude 60^0 N and stretches across Northern America, Northern Europe and Siberia. It is characterized by severe, long winters (6 to 10 months) with an average winter temperature of -34^0 C. The average summer temperature is $3\text{-}12^0$ C which enables this biome to sustain life. The growing season ranges from 50 to 60 days. Precipitation is low (6-10 inches per year) and may vary in different regions of the arctic. Precipitation may be low but it is not limiting in tundra because of the low evaporation rate and humidity remains high.

The ground remains frozen for most part of the year except in spring and summer when only the upper layer of soil thaws. The depth of thaw may vary from a few centimeters in some places to half a meter in others. Below the thaw depth there is a permanently frozen layer in the ground called **permafrost**, which is impermeable to both water and roots. Because the water cannot drain away, flatlands of tundra are wet and accumulation of water in depressions forms numerous shallow lakes and bogs. The symmetrically patterned landscape of tundra results from the action of frost. The repeated freezing and thawing (that may occur daily for long periods of time) fragments large boulders into small rocks, forms polygon shapes on the ground surface, and develops large peat mounds or small hummocks. It also causes **solifluction**, a downward slumping of soil on slopes to form terraces, or a gradual downward creep of soil and rocks that eventually rounds off ridges and other irregularities in topography. This molding of landscape by the frost action is called **cryoplanation** and is ecologically important because it makes the soil unstable and limits the kind of vegetation that can develop on it.

Vegetation. Vegetation of tundra is simple, consisting of sedges, rushes, lichens, mosses, ericaceous shrubs, flowering herbs and grasses. Perhaps the most characteristic tundra plant is the lichen known as "reindeer moss" (*Cladonia*). Most of the vegetation is perennial and reproduces vegetatively rather than by seed. The plants are generally of small size, stunted growth and compact structure. Only those species which are able to withstand extreme cold, constant disturbance of the soil and can resist desiccation and mechanical abrasion from wind, snow and soil particles can survive in arctic. Low temperature, a short growing season and low availability of nutrients result in low primary production on the tundra. Plants are photosynthetically active only for about three months out of the year, but are well adapted to low light intensities of arctic summer and can carry on photosynthesis through out the 24 hour daylight period. Although the total annual production of tundra is low because of short growing season, the daily primary production rate is quite high during the brief summer and is almost comparable to some of the temperate grasslands.

The vegetation of tundra is sufficient to provide enough food to a variety of animals, even though the diversity of species is low. The dominant herbivores are the mammals like caribou or reindeer, muskox, arctic hare, arctic ground squirrel, vole and lemming which feed on grasses, sedges and willows. Herbivorous birds are relatively few, mainly ptarmigan and migratory geese. The major arctic carnivore is the wolf which preys on muskox, caribou and lemmings. The other carnivores are arctic fox (that feed on arctic hare) and weasels (feed on lemmings and the eggs and young ones of birds). Polar beer is a marine predator and is restricted to coastal region of arctic ocean. Snowy oil and hawklike jaeger are the major avian predators. The other avian fauna includes waterfowls , sand pipers, various spp. of gulls ,snow bunting , raven and arctic terns. Many of the bird species are found near the fresh water lakes and ponds from where they get their food. Reptiles, amphibians, as well as invertebrate fauna is scarce. Insects are represented by a few genera namely mosquitoes, blackflies, moths, grasshoppers, deerflies and arctic bumble bees, but they become extremely abundant in mid-july especially the mosquitoes, blackflies and deer flies.

Animal adjustments. Animals of the arctic tundra are adapted to handle long, cold winters and to breed and raise youngones quickly in the summer. Cold blooded animals are generally acclimatized to tundra climate and remain active at freezing temperatures. Many insects pass the winter in larval or pupal stage that is especially resistant to freezing. Rotifers and some beetles remain frozen in ice for months and resume activity in summer. Large mammals and birds have thick insulating cover of pelage or plumage and a thick layer of fat. Small mammals like voles and lemmings escape the winter cold by staying in their tunnels and nests under the snow. Majority of birds and caribou avoid the severe conditions of winter by migrating southward into the boreal forest or beyond, but return to the tundra to breed.

Alpine Tundra

Climate. Alpine tundra is located on mountains throughout the world at high altitude where trees cannot grow. Tibetan plateau and Himalayan mountains constitute the largest alpine area of the world (Mani 1968). Alpine region shares many features with the arctic tundra but lack a permafrost in the sub-soil which exists only at very high elevations and in the far north.

Precipitation, especially snowfall and humidity are also higher than in the arctic tundra, but the steep topography results in rapid run off of water. Soil is thin, unstable and well drained. Average temperature is low but the difference between maximum and minimum temperature in summers may be as high as 40^0 C (Bliss 1956). The atmosphere is thin, so light intensity especially ultraviolet is high on clear days. Another unique feature of this habitat is a low atmospheric pressure and low oxygen concentration. The length of growing season is approximately 180 days.

Vegetation. Alpine vegetation varies greatly from place to place but in general lichens and mosses are less prominent; sedges, dwarf willows and grasses are more common. Cushion and mat-forming plants are more important because they are able to withstand the buffeting of the wind and can trap heat so that they can flourish while the air is still cold and prevent cold injury. At the tree line, where tundra gives way to forest, lies an area of dwarf, stunted, wind shaped trees which form a dense shrub cover (Krummholz or "crooked wood").

Fauna. Animals living in the alpine tundra are also well adapted to the prevailing conditions. Mammals are represented by pikas, marmots, mountain sheep, mountain goat, elk, yak(in Tibet), snow leopard, vole, pocket gopher and ground squirrel. Related forms of pipits, rosy finches, horned larks and other grouse like birds are found in different mountain areas of the world. As in the arctic tundra, amphibians and reptiles are uncommon but insects are fairly common and diverse. Flies and mosquitoes are scarce, but there is an abundance of springtails, beetles, grasshoppers, bugs, butterflies, ants, bumblebees, mites and spiders.

FOREST BIOME

Forest biomes are the communities that are dominated by trees and other woody vegetation, the closed strand of trees form a continuous canopy over at least 60 percent of the area. They occupy approximately one third of Earth's land area and contain about 70% of carbon present in living things. Relatively good rainfall, high humidity, optimum temperature are some of the conditions that facilitates the development of forests. All forests possess large above ground biomass which creates several layers or strata of vegetation. This vertical stratification, in turn, influence the environmental conditions like light, moisture, temperature, wind and carbon dioxide within the stand.

There are three major types of forests, classed according to latitude - coniferous forests (below the arctic tundra), temperate forests and tropical forests.

Coniferous forests

Climate and Soil. Coniferous forests mainly occur as circumpolar belt between 50^0 N and 60^0 N in northern hemisphere, found in both Eurasia and North America and are frequently termed as **Boreal forests** or **Taiga.** In Eurasia, this biome begins in Scandinavia, extends across Siberia to northern Japan. In North America, it extends across Canada and through Alaska to Brooks Range. The patches of coniferous forest are also found on all higher mountains even in Tropics. The taiga corresponds with regions of sub-arctic and cold continental climate with long, cold, dry winters (upto six months with mean temperature of -30^0 C) and short, moist, moderately warm summer (60-150 days) with mean temperature of 20^0 C. This region experiences great seasonal fluctuations of temperature, for example, Russia has recorded extremes of -90^0 F and + 90^0 F. Annual precipitation varies between 40 and 100 cm and is mostly summer rain. Boreal forest soils are thin podozols and characterized by a deep layer of litter derived from the conifer needles which decay slowly in cold temperatures. These soils are acidic, poor in nutrients and mineral deficient. Because of low evaporation, the movement of large amount of water through the soil sometimes leaches down the soluble essential nutrients (calcium, nitrogen and potassium) even beyond the reach of roots.

Vegetation. The dominant life forms of Taiga biome are the needle-leaved coniferous trees which belong to four main genera – spruce (*Picea*), fir (*Abies*), pine (*Pinus*) and larch (*Larix*), Some small deciduous trees are also common, including birches (*Betula*), alder (*Alnus*) and aspen (*Populus*) while mosses and lichens form much of the ground cover. These conical or spire-shaped needle leaf trees are adapted to withstand freezing and dry conditions of winter. The conical shape promotes shedding of snow and flexible branches bear snow-load without breaking. The needle like leaves reduces the surface area through which water may be lost (transpired) especially during winter when the frozen ground prevents plants from replenishing their water supply. The needles also have thick wax coated water-proof cuticle in which stomata are sunken and protected from drying winds. The evergreen habit (retention of foliage) allows plants to photosynthesize as soon as temperature permit in short summer growing season and intermittent warm periods of autumn and spring. The dark green of spruce and fir needles helps the foliage absorb maximum heat from the sun and begin photosynthesis as early as possible. This results in faily high annual production rate despite low temperature during half of the year. The coniferous forests are among the great lumbar producing regions of the world.

There are four major zones of vegetation within the taiga biome: the tundra-taiga ecotone, characterized by open stands of stunted spruce, lichens and moss; the open coniferous forest, characterized by lichen-black spruce woodland; the characterstic closed-canopy needle leaf evergreen boreal forest; and a mixed needle leaf evergreen-broad leaf deciduous forest which is the ecotone with the temperate broad leaf deciduous forest.

Stratification. Vertical stratification in coniferous forests is not well developed; the lower strata are poorly developed because of high crown density (that allows only a fraction of full sunlight to reach lower layers) and ground layer consists largely of ferns and mosses with few herbs. The spruce and fir forests have an upper crown of widely spaced narrow spires which is well lighted and cool because of greater air circulation. The maximum canopy development in these forests is about one-third down from this open crown that intercepts most of the solar radiation and has maximum temperature within the stand. Pine forests have a dense, well developed upper canopy that excludes so much of the solar radiation that lower strata cannot develop. However, open-crowned pines allow more light to reach the forest floor, stimulating a shrubby and herbaceous understorey.

Fauna. Among the vertebrates, mammalian predators like lynx and various members of weasel family (e.g. pine martin, wolverine, fisher, mink, ermine and sable) are the most characteristic of boreal forests; other mammals found in this region are also associated with other biomes. Snowshoe hare, varying hare, red squirrel, lemming, vole, wolf, deer, chipmunks, shrew, bat, elk, moose and beaver are other mammals common to these forests. A considerable variety of birds such as nuthatches, grosbeaks, warblers, pine siskins, crossbills, ravens, finches and sparrows are associated with coniferous forest. Reptiles are relatively rare but amphibians are relatively common in southern parts of taiga. The invertebrate fauna is dominated by a variety of insects especially the pests like bark beetles and defoliating insects (such as sawflies and bud worms) which exhibit periodic outbreaks. Mites are common in soil litter but earthworms, other annelids, millipedes and snails are scarce.

Temperate rain forest. A distinct type of coniferous forests occur along the west of North America from central California to Alaska, where temperatures are mild and seasonal range is relatively small. Although precipitation (both as rain and snow) is high (635cm/year), heavy fog is also equally important source of water. This land of high humidity, warm temperatures, nutrient poor soils, wet mild winters and dry warm summers support luxuriant growth and huge trees and is more often termed as **Temperate rain forest.** The forest is dominated by western hemlock (*Tsuga heterophylla*) western arborvitae (*Thuja plicata*), grand fir (*Abies grandis*) and

Douglas-fir. Further south, where precipitation is still high, grows the California redwood (*Sequoia sempervirens*) – the largest trees in the world.

Temperate Forests

Besides the above mentioned temperate rain forests there are other types of temperate forests – temperate deciduous forests, temperate evergreen forests, and Chaparral.

Temperate deciduous forests

Temperate deciduous forests originally covered large areas of Europe and China, parts of Japan, Australia and South America and eastern North America. The deciduous forests of Europe and Asia have largely disappeared, cleared for agriculture. This biome has witnessed extensive human interference in the name of development and, therefore, has been greatly modified and much of it has been replaced by cultivated and forest edge species.

Climate and Soil. As the name indicates, these forests are characterized by moderate climate and deciduous trees. Rainfall is plenty (75-200 cm) which is distributed evenly throughout the year. The maximum summer temperatures are 20-27^0 C which fall below freezing each winter but not usually below –12^0 C. In winter when water is scarce or the ground is frozen, deciduous trees shed their leaves to conserve water. Brown forest soils that develop under these forests are less acidic and more fertile than those of taiga because of their high levels of nitrates and other soil nutrients. The autumn leaf fall provides for an abundant and rich humus which begins to decay rapidly in spring just as the growing season begins. Although the bulk of nutrient pool is in mineral soil, the litter layer is the most important nutrient pool because it is quickly decomposed (average turnover time of four year) and recycled. Nutrients are also recycled within the tree biomass. Nutrients stored in roots are translocated and recycled through the foliage. The foliage, in turn translocates a considerable portion of its nutrients back to roots before the leaves fall.

Vegetation. Trees of this biome are distinguished by broad leaves that are shed annually and include such genera as *Quercus* (oak), *Aur* (maple), *Fagus* (beech), *Castanea* (chestnut), *Carya* (hickory), *Ulmus* (elm), *Tilia* (basswood), *Juglans* (walnut), *Betula* (birch), *Populus* (cottonwood), *Salix* (willow) and liquidamber (sweet gum). Different species of these genera occur on each continent.

Stratification. The vertical stratification is well developed in temperate deciduous forests. Five strata are recognized:

1. An **upper storey tree stratum**, 60-100 feet high, dominated regionally by various combinations of the genera listed above.
2. A **lower canopy** of small trees or sapling layer, with not only younger specimens of the tall trees but also of species limited to this layer such as shadbush, sourwood, dogwood and redbud.
3. A **shrub layer** often with members of the heath family such as rhododendron, azaleas, mountain laurel and huckleberries.
4. A **herb layer** of perrenial forbs. Often there are two blooms of herbs – spring flower which bloom immediated after winter before the trees have expanded their leaves and are gone by summer and the other flowers which are adapted to the low light levels of forest floor and lasts into the fall.
5. A **ground layer** of lichens and mosses. Lichens and mosses also grow on the trunks of the trees.

Epiphytes and lianas are few except for wild grape, poison ivy and Virginia creeper that climb the trees to flower and fruit high in the forest canopy.

The physical stratification of the forest influences the microclimate within the forest. Both light intensity and temperatures are highest in the upper canopy because this stratum intercepts the solar radiation and tend to decrease in the lower strata. However, there are seasonal variations in light intensity as well as temperature stratification. The forest floor receives its maximum illumination during early spring before the leaves appear and experience the darkest period in midsummer. In fall, maximum temperatures decrease from the canopy downward but rise again at the litter surface because the soil which is no longer shaded by an overhead canopy, absorbs and radiates more heat than in summer. During spring also maximum temperatures are found on the litter surface but decrease upward towards the canopy. Humidity is high in the forest interior during summer because of plant transpiration and poor air circulation, but lowest at the upper canopy, where air circulation, is best.

Fauna. Animal life in these forests is diverse. Many of them are adapted to arboreal life but greatest concentration and diversity of animals occur on or just below the ground layer. Among the invertebrates earthworms, millipedes, snails, land isopods and a variety of insects especially phytophagus pests (such as leaf eaters and wood borers) are common. The mammals are represented by deer, black bear, mountain lion, bobcats, red and gray fox, pig, wild boar, wolf, raccoon, opossum, skunk, vole, mice, squirrel, chipmunk, goat, antelope, bat, flying squirrel etc. The avian fauna is represented by hawks, owls, woodpeckers, chickadees, blue jay, crows, ravens, herons, storks, humming birds, warblers, wrens, thrushes, etc. The reptilian fauna is relatively impoverished compared to that in the tropics. Amphibians include newts, salamanders, toads, tree frogs and cricket frogs etc.

Like temperate plants, temperate animals are also adapted to the vagaries of the climate. Many mammals hibernate during the cold months. Birds migrate and insects enter dormancy.

Temperate evergreen forests

In several subtropical regions of the world, where humidity is high but temperature differences between winter and summer become less pronounced, are found broadleaf evergreen forests. Such forests include eucalyptus forests in Australia, forests of Central and Southern Japan, paramo forests of South America, hummocks of Florida and forests along the Gulf coast in North America. The dominant trees of temperate evergreen forests are oaks, magnolias, wild tamarind, gumbo limbo (*Bursera*) and royal and cabbage palms.

Chapparal

In mild temperate regions with abundant winter rainfall and hot, dry summers (Mediterranean climate) the vegetation is dominated by drought-resistant evergreen small thorny trees and shrubs with small leathery, sclerophyllous (hard, waxy) leaves. These communities are called **Chapparal (**for thicket in Spanish) and are found in California and Mexico, along the Mediterranean coast, in Chile, in south-western Australia and in South Africa. They are locally called **maquis** in Mediterranean region and **mallee scrub** in Australia. In California Chapparal, shrubs like chamise (*Adenostoma*) and manzanita (*Arctostaphylos*) form dense thickets alongwith several evergreen oaks. In Australia the dominant genus is *Eucalyptus*. The rainy growing season generally extends from November to May and the vegetation dries out in late summer. At this time fires burn fiercely. However, chapparal vegetation is fire adapted and sprout vigorously with the first rains. Frequent fires prevent the trees from surviving long enough to grow tall. Thus fire plays an important role in maintaining shrub dominance at the expense of trees. Some typical animals include jack rabbits, kangaroo rats, mule deer, chipmunks, lizards and many bird species. Mule deer and many birds migrate to northern regions or to higher elevations during hot, dry summer.

Although, this biome does not cover a very large total area, it contains a high number of unique species and is often considered a biodiversity "hot spot".

Tropical Forests

Tropical forests are found in equatorial regions of the world and characterized by warm to high temperatures and abundant rainfall. There are two major groups of tropical forests – tropical rain forests and tropical seasonal forests.

Tropical rainforests

Tropical rainforests are found between 10^0 N and 10^0 S latitudes at elevations below 3000 feet. They occur in three main regions: (1) Neotrophical (Amazon basin in South America to central America), (2) Africa (West and Central Africa and east coast of Madagascar) and (3) Indo-Malaysian and New Guinea (West coast of India, Assam, southeast Asia, New Guinea & Queensland, Australia) in addition to the oceanic islands present within these latitudes. These forests are among the most productive biomes of the world with a mean net primary productivity of 21.6 metric tonne/hectare/year (Golley, 1972). They exhibit a staggering diversity of life. It is estimated that one-half to two-third of all species of terrestrial plants and animals live in these forests.

Climate and Soil. Tropical rain forests are characterized by minimum seasonal changes. The variation in temperature between winter and summer is less than that between night and day. The mean annual temperature is about 26^0 C, and the difference in temperature through the year is less than 4^0 C. Rainfall exceeds 200-225 cm per year and is generally evenly distributed throughout the year. Both temperature and relative humidity remain relatively high throughout the year; relative humidity seldom drops below 60 percent. Such climatic conditions are optimum for plant activities, resulting in luxurious plant growth. Decomposition of litter is rapid but soils are subject to heavy leaching and so tend to be acidic and nutrient poor (Lucas et al, 1993). The potential nutrient loss is offset by extremely rapid uptake by the plants and the efficient direct nutrient cycling by mutualistic micro-organisms (such as mycorrhizal fungi). Tropical trees are shallow rooted, with their feeder roots concentrated in the upper 15 cm of humus and only a few penetrate the upper layer of mineral soil. Symbiotically associated with these roots are abundant mycorrhizal fungi that attach these roots to dead organic matter by hyphae and rhizomorph tissue. Through fungal hyphae minerals are transferred from dead branches or leaves to living roots. In such a direct mineral cycling, minerals remain tied up in living and dead organic matter, with only a minimum of leakage into mineral soil.

Vegetation. The flora is highly diversified especially in forests of South America and Malaysian peninsula. As compared to temperate deciduous forests where there are 5 to a maximum of 30 tree species in one hectare, tropical rain forests may have 50-100 tree species per hectare. Alwyn Gentry (1988) recorded 283 tree species in one hectare of Peruvian rain forest of which sixty three percent were represented by a singly tree each and there were only twice as many individuals as species. Trees are mostly evergreen with large dark green leaves and have smooth, straight, slender trunks which are often buttressed (swollen base). Leaves have "drip tips" at the apex to facilitate drainage of rain water off the leaves to promote transpiration. Another important feature of many tropical trees is that they are cauliflory, that is, the flowers (and hence fruits) develop directly from the trunk, rather than at the tip of branches. Large fleshy fruits of these trees attract birds and mammals that act as important dispersal agents.

Stratification. The tropical rain forest is highly stratified, exhibiting five layers or strata:

1. The **uppermost** or **emergent layer** of widely spaced trees which are 50 to 60 meters tall. The umbrella-shaped crowns of these trees rise above the rest of the forest to form a discontinuous canopy. Some of these species are deciduous during the brief dry season.

2. **Canopy layer** of 25 to 35 meter tall evergreen trees which along with the emergent layer form an almost complete canopy. Light is readily available at the top of this layer, but greatly reduced below it.

3. **Understorey tree-stratum** , 15 to 24 meters high which is often a well defined, continous layer of trees. There is little air circulation in this zone and consequently humidity is high.

4. **Shrub/sapling layer,** consisting of shrubs, young trees, tall herbs and ferns. This layer is poorly developed and in dark shade because less than 3 percent of the light intercepted at the top of canopy passes to this layer.

5**. Ground layer** of tree seedlings and low herbs. Less than 1 percent of light that strikes the top of the forest penetrates to the forest floor, hence few plants grow in this stratum.

Also abundant in these forests are the other growth forms of plants that are dependent on trees for support, and adapt different strategies to reach sunlight. These are (1) **Epiphytes** such as orchids and members of family Ericaceae which grow on branches high in the trees, using the limbs for support and taking up water, nutrients and some photosynthate from the trees, (2) **Climbers** like lianas which are the long, thick, woody vines hanging from trees like cables. They grow rapidly up the tree trunks when there is a temporary gap in the canopy and flower and fruit at the tree tops of emergent and canopy layers, and (3) **Stranglers** which begin life as epiphytes in the canopy and send their roots downward to the forest floor.

Fauna. Like the flora, the diversity of animal life also reaches its culmination in tropical rain forests. For example, in a 6 square mile area on Barro Colorado in the Panama Canal Zone, there are 20,000 species of insects compared with only a few hundred in all of France. Wilson (1987) found 43 species of ants belonging to 26 genera from a single leguminous tree in Tambopata Reserve located in Peru. Animal life, is however, largely inconspicuous, either hidden by dense foliage or because of nocturnal habit. Majority of animals are adapted to arboreal life and a smaller proportion live near the ground level (in contrast to temperate forests where majority of animals are found near the ground level). Fruits and termites are staple food for animals in these forests. The common invertebrates are snails, worms, leeches, millipedes, centipedes, scorpions, spiders, isopods, land planarians and insects. Termites and ants are dominants among insects; termites play a vital role in decomposition of woody plant material and ants are found everywhere in the forest, from upper canopy to the forest floor. Other common insects are butterflies, bees, beetles, bugs, flies, mantids and numerous orthopterans. Tropical rain forests have an abundance of amphibians like frogs (especially tree frogs) and toads and reptiles like chamaeleons, iguanas, geckos and many species of poisonous and non-poisonous snakes. Birds are largely arboreal and brightly colored and many of them are frugivorous such as parakeets, humming birds, hornbills etc. Mammals include large carnivores such as tiger, panther, leopard, jackal; large herbivores like elephant, hippopotamus, deer, tapirs, bison; arboreal mammals like monkeys, langurs, gorillas and others like bats, scaly anteater, wild pig etc.

Tropical seasonal forests

Many areas in India, Southeast Asia, Australia, Africa and South America have tropical climate of high temperature and heavy rainfall but the rainfall is not evenly distributed throughout the year and hence, there are distinct wet and dry seasons. These areas have developed the tropical seasonal forests which are also referred as **monsoon forests.** The periodic rains (monsoon) result from the outflow of dry and hot winds from high pressure areas and an inflow of moisture-laden winds from the surrounding oceans. Soils of these forests often have higher nutrient levels and are agriculturally more productive than those of a tropical rain forest. Trees are tall and stratified into two layers – canopy layer of 40m tall trees which are deciduous, shedding their leaves in dry season and an understorey tree layer of 20-30m tall trees which are evergreen. Since only the canopy is deciduous, these forests are also known as **semi evergreen seasonal tropical forests**. In India and Southeast Asia, teak is often major tree and bamboo a common shrub in these forests. Both flora and fauna of these forests are highly varied and species richness is second only to that of the tropical rain forest.

GRASSLAND BIOME

The regions of the world dominated by grasses rather than large trees or shrubs are commonly referrd as grasslands. Grasses may be tall (1.5-3.0 meter), mid (0.5-1.5 meter) or short (less than 0.5 meter). They either grow in bunches or as sod. Sod forming grasses develop a solid mat of grass over the ground while the bunch grasses develop as distinct clumps, the space between which is occupied by other plants. There are two main divisions of grassland – tropical grasslands called Savannas and temperate grasslands.

Temperate Grasslands

Temperate Grasslands occur in those regions of world where rainfall is between 25 and 75 cm/year, too low to support a forest and too high to encourage a desert. They are named differently in different regions- in Europe and Asia they are called ***Steppes*** (extends from Ukraine eastward through Russia and Mongolia); in Hungary the ***pusztas***; in South Africa, the ***veld***; in South America, the ***pampsa***; and in North America they are called ***prairie*** (towards the eastern side) and ***plains*** (towards the western side).

Climate and Soil. The grasslands exhibit pronounced seasonality both with respect to rainfall and temperature. Rainfall may be irregular but usually occurring in late spring and early summer with one or two severe drought seasons. The temperature range is very large – the summer temperatures can be well over 38^0 C, while winter temperatures can be as low as -40^0 C. The grasslands are also characterized by high rates of evaporation, periodic severe droughts and frequent fires. The soils are dark brown with a thick layer of humus. Mild leaching, high organic content and a relatively high concentration of calcium and potassium (render the soil neutral or slightly alkaline) make them the most fertile soils of the world. Because of high fertility man has converted large parts of these grasslands into agriculture land and pastures.

Vegetation. The dominant growth forms of temperate grasslands are perennial grasses – both sod forming grasses that grow by their underground stems or rhizomes (for example big blue stem, buffalo grass and wheat grass) and bunch grasses, that reproduce by seeds and without rhizomes (for example, little blue stem, june grass and needle grass). Both forms of grasses may be found in all zones but sod formers are associated with more humid grasslands and bunch grasses predominate in drier parts of the biome. Along with grasses grow perennial forbs, especially belonging to families compositae and leguminosae. Different species of grasses grow in different grasslands as determined by temperature, rainfall and soil conditions. Some of the common species of grasses include blue stem (*Andropogon*), wheat grass (*Agropyron*), switch grass (*Panicum*), slough grass (*Spartina*), needle grass (*Stipa*), drop-seed

(*Sporobolua*), June grass (Koeleria), fesque (*Festuca*), blue grass (*Poa*), grama grass (*Bouteloua*) and buffalo grass (*Buchloe*). These perennial grasses with their growth buds at or just below the surface, are well adapted to drought, cold, fire and grazing by large herbivores. The tiller or narrow, upright stem reduces heat gain in the hot summers and the intricate root system trap moisture and nutrients. The lack of trees in this biome is attributed to inadequate rainfall, large daily and seasonal temperature changes, frequent fires and grazing animals that kill woody seedlings.

Stratification. The stratification of grasslands is simple, consisting of three strata – **root layer, ground** or **mulch layer** and **herbaceous layer**. The root layer is more pronounced in grasslands than in any other major community. The bulk of the roots occupy upper 16cm of the soil but the depth to which roots of various grass species extend is considerable. Some plants are shallow rooted, seldom extending below 60cm; others go well below but seldom more than 1.5m and deep rooted ones that extend much below 1.5m. This intricate system of roots absorb moisture and nutrients from different depths in the soil. The underground rhizomes occupy the upper 10-15cm and add to the root mat in the soil. The ground layer consists of residues of herbs in various stages of decomposition (from fresh and undecayed plant remains to fragmented and partly decayed residues). This accumulated herb remains form a thick layer of mulch or detritus especially in ungrazed and unburnt grasslands. The amount of accumulated mulch is often enormous, for example on a tall grass prairie it may be two to three times the amount of annual production. Grazing and fire, however, reduce the mulch. The herbaceous layer may vary from season to season and from year to year depending upon the soil moisture. This layer itself consists of three strata – the lower layer of low-growing and ground hugging plants such as wild strawberry, violets, dandelions and mosses; the middle layer of short grasses and herbs such as wild mustard and coneflower and; the upper layer of tall grasses and forbs.

Fauna. Large mammalian herbivores are a characterstic feature of grasslands. Most of these herbivores aggregate into herds or colonies and this aggregation provides some protection against predators. The mammalian grazers come in two life forms – cursorial types such as bison and pronghorn in North America, wild horses, asses and saiga antelope in Eurasia, a variety of antelopes and zebras in Africa and kangaroos in Australia; and burrowing types such as pocket gophers, ground squirrels, prairie dogs, rabbits and mole rats. Associated with these herbivores are their predators like lions, leopards, cheetahs, hyenas, coyotes, badgers, foxes, wolves and ferrets. The characteristic birds of grasslands are prairie chickens, meadow larks, grouses, quails, sparrows, hawks and owls. A number of species of lizards and snakes are found in grasslands. The invertebrate fauna is rich and occupy all strata. The main soil inhabitants are nematodes, earthworms and ants. The above ground invertebrates include spiders, grasshoppers, locusts, leaf hoppers, beetles, bees, wasps, ants, flies etc.

Tropical Savannas

Savannas are the tropical grasslands with scattered trees or shrubs. They cover much of Central and South Africa, western India, northern Australia and some of Malaysia. Some savannas are natural, while others are anthropogenic, brought about and maintained by centuries of human interference.

Climate and Soil. Climate is the most important factor in creating a savanna. They are always found in warm or hot climates where the annual rainfall ranges from 75-150 cm, with one or two prolonged dry seasons, when fires can occur. The soils of savannas vary according to bedrock and edaphic conditions. In general, however, low fertile, laterite soils underlie these grasslands.

Vegetation. Savannas are characterized by a continuous cover of perennial grasses and forbs often 1-2m tall and are related taxonomically to those in temperate regions. The grasses and forbs die in the dry season at the same time when trees shed their leaves. Before leaf fall, nutrients especially nitrogen are translocated from leaves to the perennial roots. At the beginning of wet season, moisture releases nutrients from materials accumulated in the dry season, stimulates nutrient translocation from the roots and results in the quick growth of grasses and woody plants. The trees are often thorny or xerophilous, crooked in growth and are seldom more than 20m high. Both grasses and trees are fire-resistant and quickly recover when the rains come. Because both trees and grasses must be resistant to drought and fire, species diversity is low, in sharp contrast to adjacent tropical forest. *Panicum*, *Pennisetum*, *Andropogon* and *Imperata* are the dominant grasses. Among the trees, *Acacia* and other leguminous trees and shrubs, baobab trees(*Adansonia digitata*), euphorbias and palms dominate the African savannas. Often single species of both grass and trees may be dominant over large areas.

Fauna. The world's greates diversity (over 40 different species) of ungulates is found on the savannas of Africa. The herbivore fauna of African savannas is represented by buffaloes, wildebeast, zebras, giraffes, elephants, mice, moles, gophers, ground squirrels and numerous species of antelopes. Up to sixteen grazing and browsing species may co-exist in the same area. They do so by dividing the resources spatially and temporally; each having its own food preferences, grazing/browsing height and time of day or year to use a given area. This species-rich herbivore fauna supports a diversity of carnivores, including lions, leopards, cheetahs, jackals, wild dogs and hyenas. The large grazing herbivores are, however, missing from the South American savannas and replaced by deer, tapirs and capybara, the largest living rodent. Among the invertebrates the dominant herbivores are acrid mites, grasshoppers, ants, dung beetles and termites. Although the invertebrate herbivores are not as conspicuous as mammation herbivores, they consume a larger proportion of primary production.

DESERT BIOME

Deserts occupy about one fourth of the land area, occurring in two distinct belts around 30 latitude in both Northern and Southern hemispheres. They are found in all the continents. Major deserts are- Sonoran, Mojave, Great Basin and Chihuahuan in North America; deserts of Atacama and Argentina in South America; deserts of Alps and Scandinavian mountains in Europe; Thar desert of North-West India and Gobi desert of China in Asia; Sahara and Kalahari deserts in Africa and; deserts of central and western Australia.

Deserts are not the same everywhere and they develop under the following distinct geographic conditions-

1. Movement of air masses over earth's surface result in high atmospheric pressure over subtropical region (around 30 latitudes). Air descending from the upper atmosphere at these latitudes causes evaporation to exceed precipitation. Much of Sahara and Australian deserts have developed under such conditions.
2. On the west coasts of continents between 20^0 and 30^0 latitude, prevailing winds are easterly which prevent moist air from coming onto the west coast. Cold ocean currents also occur in these locations and moisture in the sea air condenses as fog along the shore. Some of the world's driest deserts are located on the coast; they receive most of their limited precipitation from fog. Such fog deserts include Baja California in North America, western sahara in northern Africa, Atacama in South America and Namib in southern Africa.

3. Deserts also develop under rainshadows of high mountain ranges. When air masses are forced over high mountains and downslope, they warm and their capacity for holding water vapour increases. Evaporation exceeds precipitation and an arid environment or rainshadow is created on the leeward side. Such conditions occur in Patagonian desert in Argentina and Peruvian desert.

Some of the deserts like Great Basin, interior of Sahara and Gobi desert are located in the interior of continents. They are so remote from the source of oceanic moisture that all the water has been removed from the winds by the time they reach those regions.

Climate. Deserts occur in the regions of arid climate (where evaporation exceeds precipitation) with mean annual precipitation of less than 25 cm. Rainfall is not only infrequent but unevenly distributed (highly localized) and unpredictable both in terms of when it will occur (although usually there are seasons of highest probability for rainfall) and total amount in a year.

On the basis of rainfall, deserts have been classified as **semideserts** with precipitation between 15 and 40 cm per year and plants covering 10-33 percent of ground; **true deserts** with precipitation below 12 cm per year, and plants covering 10 percent or less of the soil surface and **extreme deserts** with precipitation below 7 cm per year. Deserts with less than 2.5 cm support almost no vegetation. With little moisture to absorb and store heat, daily and seasonal temperatures can fluctuate widely. In "hot deserts" the extreme maximum temperature ranges from 43^0-49^0 C on summer afternoons but dip by 30-40 degrees at night.

"Cold deserts" have prolonged periods of below freezing temperatures and snowfall. Soil formation is poor and evaporation tends to concentrate soluble materials near the soil surface, making it highly alkaline. Sparse vegetative cover and tiny leaves add little humus resulting in low organic content of the soils which have a light gray colour. Although much of desert soil is hard and gravelly, loose soil and sand dunes are not uncommon. Typical of many deserts are the afternoon dust storms that move the sand dunes.

Plants and their adaptations. Shrubs are the dominant growth forms of deserts. They have short, woody trunks from which arise numerous branches bearing small thick leaves that are shed during prolonged dry periods. They also possess shallow, but extensive root systems adapted to quickly absorb surface water whenever it rains. Some of the desert shrubs are deep rooted such as mesquite (*Prospis*) and *Tamarix*, whose tap roots extend downward 20 to 30 feet to reach the ground water supplies, rendering them independent of water supplied by rainfall. The shrubs form an open canopy and, except after rains when annuals may cover the desert floor, the ground between them is bare of vegetative growth. The spacing reduces competition for scarce resources. The desert shrubs present the same general apperance throughout the world, even though species may belong to diverse taxa. Some common desert shrubs are saga bush, bud sage (*Artemisia*), cresote bush, acacia, and ocotillo (*Fouquieria*).

Another important growth form of deserts is the succulent. **Succulents** store water accumulated during rains for use during the intervening dry periods. Different species store water in different parts of the plant – in stem, root, leaf and fruit. Most prominent are the stem succulents such as cacti, yuccas and succulent euphorbias and leaf succulents such as agaves and aloes. Most succulents can not tolerate freezing temperatures, hence are restricted only to hot deserts. Also adapted to desert conditions are the **ephemerals**. These are short lived annual forbs which complete their life cycles in two-three weeks when moisture and temperature are favorable. During draught periods they persist as seeds which are encased in a waterproof coating that prevents desiccation for years if necessary. The scarcity of vegetation make deserts the least productive biomes of the world; mean net primary productivity is 90.0 gm/m^2 /yr (Whittaker, 1975).

Animals and their adaptations. Inspite of aridity, deserts support a surprising diversity of its animal life that is well adapted to scarcity of water and food and extremes of temperature, especially the mid-day temperature of hot deserts. Most animals are generalists and opportunists in their mode of feeding. Herbivores consume a wide range of plants and their parts and as a last resort may consume dead litter and lichens. Specialist carnivores are few and most non-herbivorous animals are omnivores, having mixed diets. The characteristic animals of the desert are the small herbivorous rodents and reptiles. Mammals as a group are not very well adapted to desert conditions, yet certain species have developed remarkable secondary adaptations. Among the successful desert mammals are the rodents such as kangaroo rat (*Dipodomys*), pocket mouse (*Perognathus*), jerboa (*Dipus*), wood rat (*Neotoma*) ground squirrel, and various species of mice. Besides rodents, the other mammals include rabbits, hedgehogs, camels, foxes, coyote and badger. Many mammals are nocturnal or crepescular and remain in burrows during the heat of the day. They conserve water by excreting very concentrated urine. Some mammals like kangaroo rat, pocket mouse and jerboa can live indefinitely on dry seeds and do not need to drink water while others like desert rabbits and wood rats meet their water need by consuming succulent cacti or other plants that store water. Large mammals which cannot live long without drinking water are restricted to the vicinity of springs or ponds in the desert. Camels can endure long periods without water because their body tissues can tolerate an elevation of body temperature as much as 6^0 C (without increasing the rate of evaporation) and a degree of dehydration that would be fatal to most animals. Birds are less common but the reptiles are numerous and diverse. Reptiles with their relatively impervious skin, production of uric acid instead of urine and ability to gain body heat directly from the sun and to retreat to shade or underground to avoid heat are exceptionally well adapted to these dry lands. Lizards and snakes are important predators of ants, birds and rodents. Desert insects are "waterproofed" with heavy wax and have internally invaginated spiracle system to minimize the water loss. The invertebrate fauna of deserts is represented by ants, termites, beetles, grasshoppers, spiders and scorpions.

AQUATIC BIOMES

Water covers nearly 70% of the earth's surface, providing abode to numerous species of organisms. In contrast to terrestrial biomes, which are identified and classified on the dominant vegetation, aquatic biomes are distinguished on the basis of physical attributes such as salinity, strength of current, availability of light and oxygen content. Global aquatic ecosystems fall into two broad categories– the freshwater biomes and marine biomes.

FRESHWATER BIOMES

Freshwater regions occupy a relatively small portion of the Earth's surface (less than 5%) as compared to marine and terrestrial habitats but their importance to humans is greater than their relative area because they are the most convenient and cheapest source of water for domestic and industrial use and provide a convenient and economical waste disposal system. Freshwater habitats are divided into two groups – ***lentic*** or standing-water ecosystems such as lakes and ponds and ***lotic*** or running-water ecosystems such as springs, streams and rivers. Associated with lentic and lotic ecosystems are the ***wetlands***, where water is at or near the surface or the land is covered by shallow water such as swamps, marshes and bogs.

Lentic ecosystems

Lakes and ponds are inland depressions containing standing water. They are geographically isolated from one another and scattered throughout the earth's surface. They vary in size from just a few square meters to thousands of square kilometers and range in depth from one meter to over 1000 meters. Lake Baikal in Siberia is the deepest lake with a maximum depth of 1620 meter and a mean depth of 740 meter. The distinction between ponds and lakes is blurred, but for convenient reference ponds may be defined as small bodies of standing water so shallow that rooted plants can grow over most of the bottom. The life span of ponds ranges from a few weeks or months for small seasonal or temporary ponds to several hundred years for larger ponds. Although a few lakes, such as lake Baikal, are ancient, most large lakes dates back to Pleistocene glaciation.

Stratification/Zonation. *Lentic ecosystems have well defined boundaries – the shoreline, the sides of the basin, the surface of the water and the bottom sediment and have characterstic vertical and horizontal stratification/zonation. Unlike terrestrial ecosystems where stratification is defined by vegetation, in aquatic systems it is determined by physical factors like light and temperature. A lake has two zones based on the availability of light. The upper layer to which light penetrates is the autotrophic or euphotic zone and below this is* aphotic zone *where heterotrophs live and subsist on the rain of material from above. The depth of euphotic zone depends on the availability (which changes with season) and penetration of light. Light penetration, in turn, is determined by turbidity produced by sediments and phytoplankton.*

Water has unique thermal properties such as – (i) maximum density at 4^0 C, (ii) high specific heat, (iii) high latent heat of fusion, (iv) high latent heat of evaporation and (v) high thermal conductivity – all of which combine to minimize temperature changes. Thus the range of temperature variation is smaller in water than in air. Temperatures vary seasonally and with depth. In temperate regions lakes often become thermally stratified during summer and again in winter (Figure 3.2).

In summer, the high atmospheric temperature warm the upper layer of water and the wind mixes this water well. This upper, warm, circulating layer of water is called **epilimnion.** Below this lies denser, cold, non-circulating water layer called the **hypolimnion**. Between these two layers is a zone of steep temperature gradient called **thermocline**, that acts as a barrier to the exchange of materials. Consequently, the supply of oxygen in the hyplimnion and of nutrients in the epilimnion may become short. In autumn, atmospheric temperature decreases, the upper layers cool and as their density increases, they sink and force the bottom layers upward. The water in the lake is thoroughly mixed by this action and by strong winds, the thermocline disappears and oxygen and nutrients are circulated. This is known as **autumn overturn**.

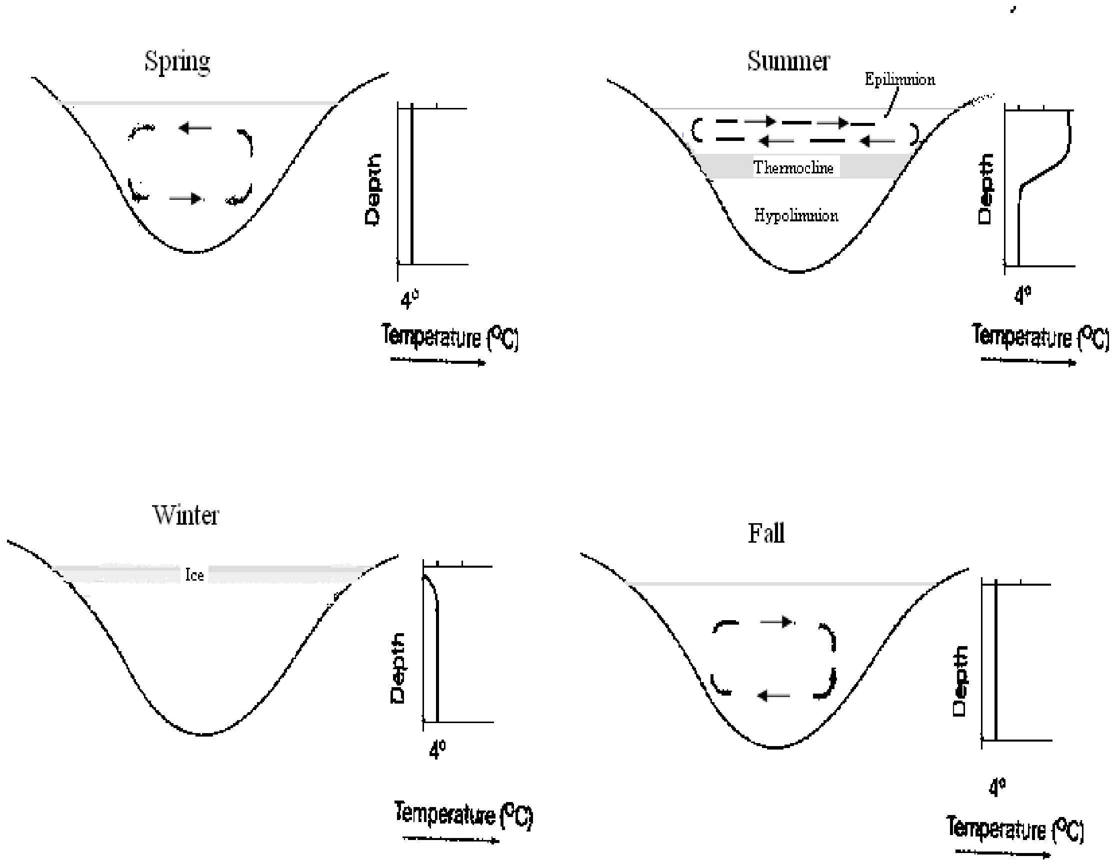


Figure 3.2 - Seasonal temperature profile and stratification in temperate lake.

In winter the air temperature drops below 0^0 C and the surface of lake freezes and no turnover of water occurs; once again a gradient (0^0 C to 4^0 C from top to bottom) is set up. Oxygen supply is usually not greatly reduced in the lake in winter because bacterial decomposition and respiration of organisms are not so great and water holds more oxygen at low temperatures. Then, as spring returns, the ice melts, water becomes warmer and heavier and sinks, producing another mixing called the **spring overturn**. Blooms of phytoplankton often follow the spring and autumn overturns, as nutrients from the bottom become available in the euphotic zone. This yearly pattern of two overturns (spring and autumn) and two stagnation periods (summer and winter) is not found in tropical and polar lakes. The surface temperature of subtropical lakes never fall below 4^0 C, and they exhibit a distinct thermal gradient from top to bottom and only one circulation period per year, which comes in winter. Tropical lakes with high surface temperatures (20^0 C-30^0 C) exhibit weak gradients and little seasonal change in temperature at any depth. Even this weak temperature gradient, however, may produce a stable stratification through out the year and the mixing of water is irregular, occurring in cooler seasons. Very deep tropical lakes tend to remain only partly mixed. Polar lakes, on the other hand, have surface temperature below 4^0C for most part of the year except during the brief period of summer when the circulation of water takes place.

Typically lakes and ponds can be subdivided into following zones based on the depth and distance from the shoreline (Figure 3.3) –

Figure 3.3 - Different zones of a lentic ecosystem.

(a) **Littoral zone –** It is the shallow water zone near the shore of a lake or pond in which light penetrates to the bottom. It is typically occupied by rooted and floating aquatic plants.

(b) **Limnetic zone** – It is the near-surface open water zone that is surrounded by littoral zone and extends upto the depth of effective light penetration. This zone is dominated by plankton, both phytoplankton and zooplankton. Both littoral and limnetic zones constitute the euphotic zone where production is greater than respiration (P/R >1).

(c) **Profundal zone** – The deep water zone which is beyond the depth of effective light penetration is the profundal zone where respiration is greater than production (P/R< 1). Between the limnetic and profundal zone is a level at which P/R=1 and is known as **compensation level**.

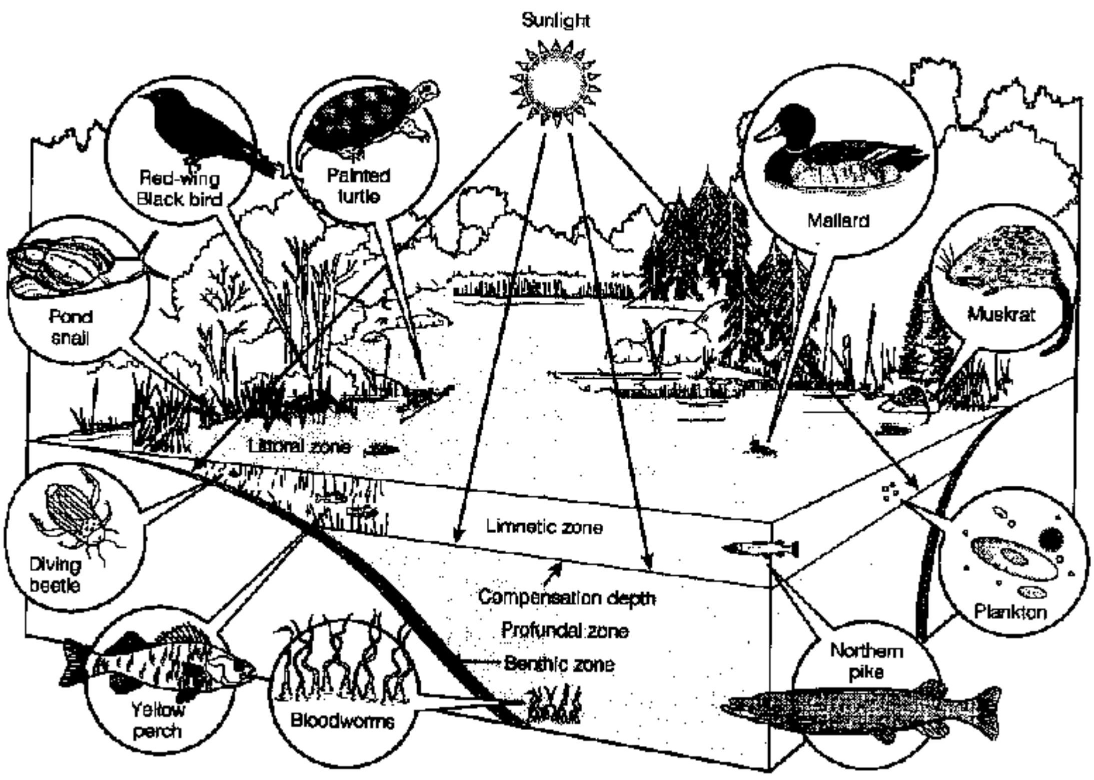
In ponds the littoral zone is relatively large and the limnetic and profundal zones are small or even absent

Benthic zone – The bottom region of both littoral and profundal zones is the benthic

zone which is the zone of decomposition.

Flora and Fauna. The distribution and abundance of life in lentic habitats is largely influenced by the availability of light, oxygen and nutrients which vary in different zones, resulting in distinct biotic communities in these zones. Although many aquatic organisms are free to move from one part of aquatic body to other, majority of them restrict themselves to a particular zone.

Biota of littoral zone . Aquatic life is richest and most abundant in the littoral zone. Plants of this region are of two main types – rooted or benthic plants (mostly seed plants) and phytoplankton or floating green plants (mostly algae). Sometimes the floating plants like duckweed, Lemna (a neuston spermatophyte, not attached to bottom) may form a continuous



sheet over the surface of littoral waters, shading out all other green plants. Typically the rooted aquatics form concentric zones within the littoral zone (Figure 1.4 and accompanying text), one group replacing another as the depth of the water changes. The shallow water close to the shore is the zone of emergents, plants whose roots and stems are immersed in water and whose upper stems and leaves project above the water. Thus, they obtain carbon dioxide from air but other nutrients from water sediments. Among these emergents are plants with narrow, tubular or linear leaves, such as bulrushes (Scirpus), cattails (Typha), arrowheads (Sagittaria), bur reeds (Sparganium), spikerushes (Eleocharis). These plants together with the plants on the shore form an important link between water and terrestrial environment. They are used for food and shelter by amphibious animals. Out in slightly deeper water are the rooted plants with floating leaves such as water lilies (Nymphaea) and smartweed (Polygonum). Their horizontal leaves may reduce the light penetration into water, but undersurfaces provide resting places and places for egg deposition by animals. They offer food and support for numerous herbivorous animals. Still deeper in the littoral zone is the zone of fragile thin-stemmed rooted plants that are completely or largely submerged. Submerged vegetation includes plants like Potamogeton, Elodea, Vallisneria, Ceratophyllum, Myriophyllum, Najas, Hydrilla, Chara etc. The phytoplankton of littoral zone is chiefly composed of diatoms (e.g Navicula, Fragilaria, Cyclotella), blue green algae (e.g. Microcystis, Anabaena, Oscillatoria), green algae (e.g. Senedesmus, Closterium, Cosmarium, Spirogyra, Zygnema, Oedogonium) and holophytic protozoa (e.g. Euglena).

There is greater concentration and diversity of animal life in littoral zone than in the other zones. Representatives from all aquatic life forms viz. plankton, nekton, neuston, periphyton and benthos are found here. Zooplankton are represented by protozoans like Paramecium, Vorticella, Stentor; cladocerans like *Daphnia, Bosmina*; copepods like *Cyclops*; rotifers such as *Keratella*, *Brachionus*, *Asplanchna* ; and ostracods. Among the periphyton forms are pond snails, damsel fly and dragon fly nymphs, rotifers, flatworms, hydra and midge larvae which rest on or are attached to stems and leaves of large plants. The free swimming fauna includes invertebrates such as adult and larval beetles, adult hemipterans and dipteran larvae and pupae. Among the vertebrates are the frogs, salamanders, turtles and water snakes which are exclusive to littoral zone and the fishes that move freely between littoral and limnetic zones. Many fishes such as sunfish, top minnows, bass, pike and gar spend much of their time in the littoral zone and some even make territories and breed in this zone. Neuston of littoral community are the whirling beetles, water striders and numerous protozoa.

Biota of limnetic zone. Plankton and nekton are the chief biotic forms of the limnetic zone. In the absence of macrophytes, phytoplankton are the only producer organisms on which the rest of limnetic life depends. Phytoplankton consist of diatoms, desmids, filamentons green algae and the green flagellates, mainly the dinoflagellates,eugleinids and volvocids. They exhibit marked seasonal variations in the population density. In response to favourable temperature, light and nutrient conditions very high densities appear quickly and persist for a short time and are called phytoplankton “blooms” or “ pulses”. In temperate lakes, two blooms are observed – one in early spring and another in autumn. The phytoplankton blooms are generally followed by zooplankton blooms as the latter are directly dependent on the former for food. The limnetic zooplankton are mainly cladocerans, copepods and rotifers. A characterstic feature of these zooplankton is the vertical diel (24 hr periodicity) migrations. Depending upon the species and stage of development, they spend the night or day in the deep waters and moves upto the surface during alternate period to feed on phytoplankton.

Fishes constitute the bulk of nekton in limnetic zone. They may be the same as those of littoral zone but in large lakes, a few may be restricted to the limnetic zone only. Their distribution is influenced mostly by food supply, oxygen and temperature. During the summer some like large-mouth bass, pike and muskellunge inhabit the warmer epilimnion waters, where food is abundant. In winter they retreat to deeper water. Others like lake trout move to greater depths as summer advances. When oxygen and temperature are fairly uniform throughout the lake, both warm-water and cold- water forms occupy all levels.

Biota of profundal zone . *Profundal zone is the heterotrophic zone of lake. Since there is no light, producers are absent and the consumers are mainly detritus feeders and carnivores. The life in profundal zone is influenced by oxygen, temperature, and the amount of organic matter and nutrients supplied from the limnetic and littoral zone above. In highly productive waters decomposer organisms so deplete the profundal waters of oxygen that little aerobic life can exist there. However, in a deep lake where profundal zone is relatively much larger, the productivity of the epilimnion is low in comparison to the volume of water and decomposition does not deplete the oxygen. Here the profundal zone supports some life, particularly fish and plankton. Some zooplankton may occupy this zone only during some part of the day, but migrate upward to the surface to feed.*

Biota of Benthic zone. The bottom of lake is a decomposition zone where the dead bodies of plants and animals, organic debris and the materials washed in by inflowing water settle. The major community constituents are bacteria and fungi, which are especially abundant in the water–mud interphase where organic matter accumulates, and the animals like chironomid larvae, bottom dwelling annelids, clams etc. Bottom of profundal zones of highly productive lakes have anaerobic conditions due to a greater accumulation of organic matter that can be utilized by bottom fauna. Under such anaerobic conditions hardly any life (except anaerobic bacteria) exist. Life in the bottom ooze is most abundant in lakes with a deep hypolimnion in which oxygen is still available.

As the water becomes more shallow (the bottom of littoral zone) increased oxygen, light and food increases the diversity and abundance of species not found on the profundal bottom. Closely associated with the benthic community are the periphyton which are found moving on or attached to leaves of submerged plants, sticks, rocks and other debris. They consist primarily of blue-green algae, diatoms, water mosses and sponges.

Nutrient Cycling and Productivity. Lentic ecosystems are strongly influenced by the movement of nutrients in and out of the basin. Nutrient inputs are in the form of wind borne particulate matter, particulate matter washed into the basin from surrounding terrestrial water shed, dissolved nutrients in rain, snow, groundwater and inflowing streams and atmospheric gases. Nutrient outputs are mainly the dissolved and particular matter carried out of the basin by out-flowing waters and nutrients incorporated into deep sediments which may be removed from circulation for a long period of time and gases such as carbon dioxide and methane lost to atmosphere. The lentic ecosystem receives its water from precipitation and drainage from surrounding areas. Water is lost from the system through evaporation, evapotranspiration, seepage through walls of the basin and subsurface flows. Within the lentic ecosystem nutrients move among three compartments – dissolved organic matter, particulate organic matter and primary and secondary minerals. Both nutrients and energy move by way of grazing and detrital food chains. Lakes, like terrestrial communities, are dominated by detrital food chain, with bulk of detritus contributed by littoral zone.

Primary production in lakes is carried out by phytoplankton in limnetic zone and by macrophytes in littoral zone. Producation by phytoplankton is influenced by nutrient availability in the water column. If nutrients are not limiting the net photosynthesis (excluding the respiratory utilization) by phytoplankton and their biomass increases. However, as phytoplankton biomass increases, shading increases, respiration per unit surface increases and net photosynthesis and thus production declines. When nutrients are low, net photosynthesis and biomass decreases. However, if zooplankton grazing and bacterial decomposition are high, nutrients are recycled rapidly, resulting in a high rate of net photosynthesis even though the concentration of nutrients and biomass accumulation are low. Macrophytes also contribute to lake production but their contribution is influenced by the fertility of the lake. Highly fertile lakes support heavy growth of phytoplankton that shades out macrophytes and reduces their contribution. In less fertile lakes where phytoplankton production is low, light penetrates the water and rooted aquatics grow. Unlike phytoplankton, macrophytes are little affected by nutrient exchange in the water column because they draw the nutrients directly from the sediments.

Based on primary productivity lakes may be classified into two broad categories –

Oligotrophic lakes – These are deep lakes having low surface to volume ratio with the hypolimnion larger than the epilimnion. Water is clear and appear blue to blue-green in sunlight. Bottom sediments are largely inorganic. The nutrient content of the water is low. Low nutrient availability results from a low input of nutrients from external sources and this causes low primary productivity. Littoral plants are scarce and plankton density is low. Plankton blooms are rare since nutrients rarely accumulate sufficiently to produce a population eruption of phytoplankton. Low organic production results in low rate of decomposition and high oxygen concentrtion in the hypolimnion. The lack of decomposable organic substances results in low bacterial populations and slow rates of microbial metabolism. Although the number of organisms in oligotrophic lakes may be low, the diversity of species is often high.

Eutrophic lakes – These are shallow lakes with high surface to volume ratio. They are rich in nutrients, especially nitrogen and phosphorus, that stimulate a heavy growth of algae and other aquatic plants and result in high primary productivity. Littoral vegetation is more abundant and plankton density is high and such lakes exhibit characteristic plankton blooms. Phytoplankton become concentrated in the upper layer of the water, giving it a green colour. The turbidity reduces the light penetration and restricts biological productivity to a narrow zone of surface water. Dead organic matter accumulates on the lake bottom where bacteria convert the dead matter into inorganic substances. The activities of decomposers deplete the oxygen level to a point where the aerobic life cannot exist. The number of species declines in such lakes although the number and biomass of organisms may remain high. The high rate of decomposition speeds up cycling of nutrients that further increases plant production. This natural filling in of lake basin with organic matter and nutrient enrichment is termed as **eutrophicatio***n*. Eutrophication, however, can be speeded up by human influences, which increase nutrient concentrations through the introduction of heavy infuse of wastes, raw sewage, drainage from agricultural lands (having high content of fertilizers) and booming of fossil fuels. This human-produced accelerated enrichment, which results in chemical and environmental changes in the lake, is often termed **cultural eutrophication**.

Lotic ecosystems

Streams and rivers are the bodies of continuously flowing water moving in one direction. They get their start at headwaters, which may be springs, snowmelt or even lakes, and then travel all the way to their mouths, usually another water channel or the ocean. The direction of flow is dictated by the lay of land, the underlying rock condition and the slope. Fast flowing water moving downstream cause extensive erosion that cuts the channel wider and deeper, and carries lot of debris that sooner or later are deposited within or along the stream where flow of water is less. Lotic system is an open ecosystem in which land-water interchange is relatively more extensive than other aquatic ecosystems. The major source of energy and nutrients is in the form of detritus carried into the streams from the surrounding land. Sometimes they also receive plankton and detritus from the connected lakes and ponds. The energy is exported from the streams in the form of emerging insects (the larval and nymphal stages of which are residents of streams) and the stream organisms removed by air breathing predators. Flowing water prevents accumulation of nutrients that continue to drift downstream. Current, is thus, a major controlling and limiting factor. Current molds the character of the stream and influences the life. The velocity of current varies from stream to stream and within the stream itself and it depends upon the size, shape and steepness of the stream channel, the roughness of the bottom, the depth and the rainfall.

Zonation. Unlike ponds and lakes where both vertical stratification and horizontal zonation are prominent features, streams and rivers are neither stratified nor exhibit horizontal zonation. However, in a given stretch of stream two zones are generally recognized:

Rapid Zone – It is the shallow water zone where the velocity of current is so high that it keeps the bottom clear of silt or other loose material, thus providing a firm substrate. This zone is occupied by specialized organisms that become firmly attached or cling to the substrate or that can swim against the current.

Pool Zone – It is the deep water zone where the velocity of current is reduced so that sand and silt settle, providing a soft bottom favourable for burrowing and swimming animals, rooted plants, and in large pools, plankton.

Lotic Biota. The dominant producers in fast flowing streams and rivers are the aufwuchs or periphyton consisting chiefly of diatoms, blue-green and green algae, and water moss that grow over rocks and rubble on the streambed. Many small algal species are epiphytes on other algae. The swift current, however, tears away large part of algae and the epiphytes and as a result, there is constant contribution from upstream to the downstream. Only in those parts of rivers where current is slow that phytoplankton develop. The low primary productivity, however, does not limit the oxygen. Because of small depth, large surface area exposed to air and constant motion streams generally have an abundant supply of oxygen and thus support a large variety of heterotrophic organisms. A major source of energy and nutrients is detrital material entering from the watershed and nutrients leached from adjoing forest, agricultural and residential land. Supplementing this detrital input is the detritus contributed by autotrophs of stream. Much of the organic matter is in the form of leaves and woody debris dropped from streamside vegetation which are collectively called coarse particulate organic matter (CPOM – particles larger than 1 mm). Bacteria and fungi grow on these large organic particles and degrade cellulose and lignin. A major consumer of CPOM are the **shredders** such as larvae of craneflies and caddisflies, nymphs of stoneflies and crayfish that feed on softer portion of leaves and other large organic particles and break them into smaller particles. Broken up by shredders and partially decomposed by microbes, the leaf material along with fecal matter of shredders and other heterotrophs become part of fine particulate organic matter (FPOM – particle size less than 1 mm). FPOM is picked up by another group of stream invertebrates, the **collectors** such as larvae of black flies and midges, and the net spinning caddisflies. Whereas shredders and collectors feed on deterital material, **grazers** (e.g. beetle larvae) feed on algae and mosses attached to stones and rubble. Feeding on detritovores and grazers are the **predators** such as large stonefly and dobsonfly larvae, stream salamanders and fishes. Because of current CPOM, FPOM and invertebrates tend to drift downstream and form a traveling benthos. Farther downstream where current is slow are also found the sessile invertebrates and those that burrow in softer substrate, such as clams and burrowing mayfly nymphs. The prominent vertebrates in lotic waters are the fishes of various types such as darters, trout, salmon, carps and catfishes.

Organisms of lotic waters show adaptations for maintaining position in swift water. Some of these important adaptations are:-

Permanent attachment to a firm substrate – In fast running water, the plants and animals are permanently attached to substratum such as rocks, stones and logs. Plants of streams such as algae, mosses and encrusting diatoms are found attached to stones and logs. A few animals such as freshwater sponges, coelenterates (e.g *Hydra*) and caddis fly larvae are found fixed to stones.

Presence of hooks and suckers – Certain animals have hooks and suckers to grip the substratum. Larvae of *Simulium* and *Blepharocerca* have well developed suckers to gain firm hold on substratum that prevent them from drifting away with current. The larvae of *Hydropsyche* (net spinning caddis fly) not only has hooks but also form a net around itself that acts as shelter and also as a food trap for suspended food particles in water.

Sticky undersurface – Snails and flatworms have sticky undersurfaces with the help of which they adhere to submerged objects.

Streamlined body – Nearly all stream animals have streamlined body (broadly rounded in front and tapering posteriorly) that offer little resistance to water flowing over it.

Fllatened body – Many animals living in streams have flattened bodies which help them to take shelter and refuge under stones and in crevices. This is especially seen in the nymphs of mayfly and stonefly.

Positive rheotaxis – Stream animals are invariably positively rheotactic i.e. they orient themselves upstream and move against water current.

Positive thigmotaxis – Many stream animals exhibit positve thigmotaxis i.e. they have an inherent tendency to cling close to a surface or to keep the body in close contact with the surface.

River Continuum. The lotic ecosystem is essentially a continuum of physical and biological conditions from the headwaters to the river’s mouth. These changing conditions in the gradient from small to large streams has been termed the **river continuum concept** (Cummins 1977; Vannote et al. 1980) (Figure 3.4). Headwater streams are usually small, swift, cold and often completely shaded so that little light is available for autotrophic production. The water is also clearer and has high oxygen levels. The high velocity of current is eroding, resulting in hard rocky substratum without sediment. Dominant organisms are shredders, feeding on CPOM, and collectors that process FPOM. Populations of grazers are small because of low autotrophic production and predators are mainly small, cold water fishes – sculpins, darters and trout. The headwater ecosystem is heterotrophic, with a P/R ratio of much less than one.

The middle parts of stream/river are wider, no longer shaded and warmer. There is a decrease in organic matter input from watershed but an increase in light and temperature results in algal and rooted plant production. Community metabolism shifts from heterotrophy to autotrophy with P/R ratio of one or more. Because of the lack of CPOM, shredders disappear, and collectors, feeding on FPOM transported downstream, and grazers, feeding on autotrophic production, become the dominant consumers. Cold-water fishes are replaced by warm-water fishes. Species diversity reaches its peak in the midsections of river/stream.

In the lower reaches, the river is wider and deeper. The volume of flow increases but the current becomes slower and sediments accumulate on the bottom. The water is usually muddy, thereby decreasing light penetration and aquatic photosynthesis. The stream again becomes heterotrophic (P/R< 1). Dominant organisms are the bottom dwelling collectors, feeding on FPOM. The slow and deep water conditions support some plankton growth. Warm-water fishes such as carps and catfishes which are well adapted to low oxygen levels of this region are abundant, but the overall species diversity (both flora and fauna) is low.

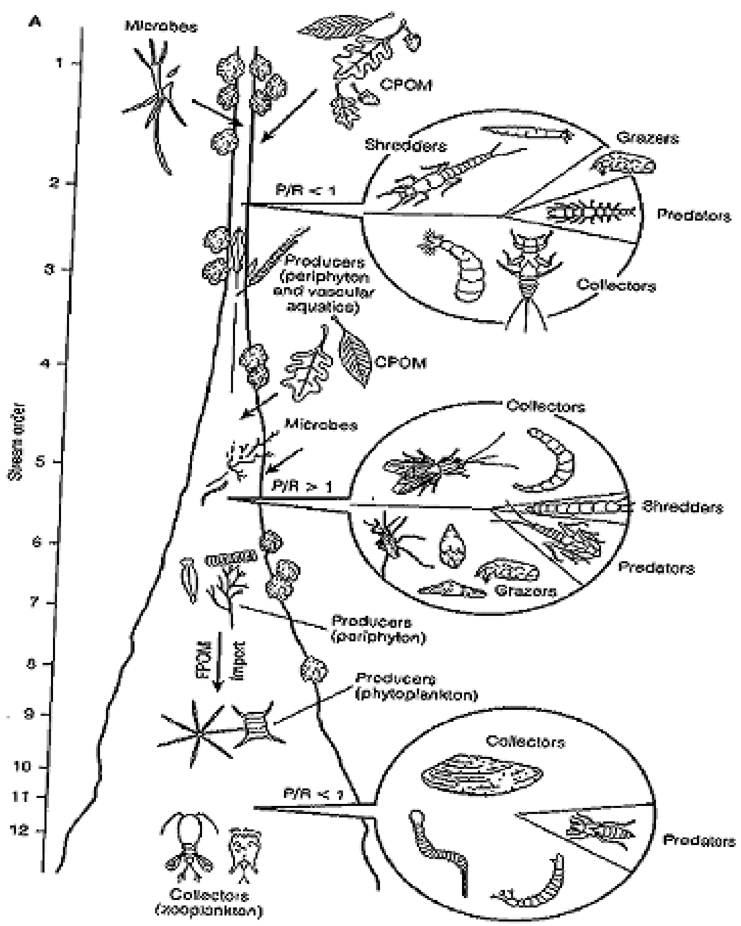


Figure 3.4 - The river continuum depicting stream order and longitudinal changes in different feeding types of organisms, particulate matter and community metabolism.

Wetlands

Wetlands are the lands transitional between terrestrial and aquatic systems and thus exhibit some of the characteristics of each. These are the ecosystems in which land surface is saturated or covered with standing water at least part of the year during which time they support predominately hydrophytes. The periodic fluctuations in water level influences the productivity and species composition of wetland community. There are many kinds of wetlands which can be grouped into three major categories: swamps, marshes and peatlands.

Swamps are the wetlands with wooded vegetation (trees and shrubs). They may be deepwater swamps dominated by swamp oaks and cypress trees; or they may be shrub swamps dominated by alder and willows; or they may be forested woodlands along large river systems that are occasionally flooded by river waters.

Marshes are the wetlands dominated by emergent vegetation, plants with roots in soil (which is covered part or all of the time by water) and leaves held above the water. There are no trees in marshes and dominant vegetation are reeds, sedges, grasses and cattails. They develop along margins of lakes and ponds or in shallow basins with an inflow and outflow of water, along slow moving rivers, and on tidal flats along the lower reaches of large rivers in coastal plains. Marshes support a rich fauna of amphibians, reptiles, birds and furbearing mammals. They are the breeding and wintering grounds for ducks, geese, herons, shorebirds and muskrats and as stopover points for migrating waterfowl and shorebirds. Coastal freshwater marshes function as nurseries for many fishes such as herring, shad and striped bass. Productivity of marshes is influenced by the periodicity of water-level fluctuations, soil, nutrient availability and types of vegetation. Marsh vegetation acts as a nutrient pump, drawing nutrients from the substrate, translocating them into the shoots and releasing them to the surface soil by leaching and death of shoots. In this way marsh plants make nutrients sequestered in the soil available for growth. Initial decomposition in marshes is high because leaching removes the soluble compounds that become part of dissolved organic matter. Productivity of marshes is, this, much higher than of surrounding uplands.

Peatlands are the waterlogged areas saturated by groundwater or rainwater in which there is an accumulation of partially decayed organic matter. Peatlands fed by water moving through mineral soil dominated by sedges and slightly acidic are called ***fens***. Peatlands dominated by *Sphagnum* mosses, receiving their water supply largely from precipitatin and highly acidic are called ***Bogs***. Although fens receive most of their nutrients from mineral soil, bogs depend on precipitation for nutrient inputs. Rate of decomposition is slow especially of *Sphagnum*. The accumulation of plant matter in an undecomposed state result in the energy and nutrients being locked up in peat. Because of low temperatures, acidity and nutrient immobilization, primary productivity in peatlands is low. The dominant herbivores of bog community are insects, grouse, hares, bog lemmings and sheep, and the predators include spiders, ground beetles, frogs, shrews, warblers, weasels and owls.

Although we have included wetlands as part of freshwater ecosystem, there are some which have high salt concentrations such as inland saline marshes, coastal salt marshes and mangrove swamps. These support various kinds of salt-tolerent grasses and also such animals like shrimps, shellfish etc.

Although wetlands occupy only 2 percent of the surface area of earth, they play important role in global cycling of sulfur, nitrogen, phosphorus and carbon. The major anaerobic decomposers (fermenters, denitrifiers, sulfate reducers and methane producers) gasify – and thereby recycle into the atmosphere – carbon, nitrogen and sulfur. Phosphate is also converted from insoluble forms to soluble forms that are more easily available to organisms. Wetlands also provide an important ecological service in storing flood waters. They also improve water quality by acting as natural water purification systems, removing silt and absorbing nutrients and toxins. They also exhibit high species diversity and are the breeding and nesting sites for a number of endangered species.

MARINE ECOSYSTEMS

Marine regions cover about 71% of the earth's surface and include oceans and associated ecosystems like estuaries, tidal marshes and swamps, sea shores and coral reefs. Oceans are the largest of all ecosystems and play a key role in controlling the worls's climates, the atmosphere, and the functioning of major mineral cycles. An important feature of sea is that it is very deep and life extends to all its depth but is much denser near the margins of continents and islands. All oceans are interconnected and the physical factors like temperature, salinity, and depth are the chief barriers to free movement of marine organisms. The important physical factors that influence life in marine environments are listed as follows:-

Salinity – The average salinity of sea water is 35‰ of which about 80% is contributed by sodium chloride and the rest by calcium, magnesium and potassium salts. The major anions in sea water are chloride, sulfate, bicarbonate, carbonate and bromide. In addition minute quantities of numerous other elements are present in oceans. Sea water is alkaline (pH=8.2) and is also strongly buffered. Most marine species are well adapted to live in high salinities. Although salinity varies within very narrow limits in the open ocean but is quite variable in estuarine waters. Organisms of open ocean are usually stenohaline whereas organisms of inshore brackish waters are generally euryhaline. Marine invertebrates, elasmobranchs and bony fishes have adopted different strategies to face the problem of osmoregulation in marine environment.

Light – Light is an important factor in the life of marine organisms due to its influence on photosynthesis, heating, radiations and vision. The volume of surface area lighted by sun is small compared to the volume of water in ocean. Light penetrates only upto 100-200 metres, the upper thin **Euphotic zone** which is the 'producing zone' rich in phytoplankton, primary and secondary consumers. Below 200 metres is the vast **Aphotic zone** in which producers are absent and heterotrophs are mainly secondary consumers.

Temperature – Ocean is the largest store house of sun's heat and thus regulates the temperature of the world. The range of temperature in sea is far less than that on the land; the extremes of temperature ranges from –3° C to 40° C. Arctic waters at 27^0 F are much colder than tropical waters at 81° F, and currents are warmer or colder than the waters through which they flow. Seasonal and daily temperature changes are larger in coastal waters than in the open sea. The surface of coastal water is coolest at dawn and the warmest at dusk. At any given place, the temperature of deep water is almost constant cold; bottom water of the deep sea may be about –1° C. Although temperature difference in the sea is not very pronounced, yet it acts as effective barrier for the distribution of animals.

Pressure – Pressure in the ocean varies from 1 atmosphere at the surface to 1000 atmosphere at its greatest depth and this has a pronounced effect on the distribution of life. Certain organisms are restricted to surface waters, whereas others are adapted to pressure at great depths. Some marine organisms, such as sperm whales and certain seals are eurybathic which can dive to great depths and return to the surface without difficulty.

Waves and Tides – They have their maximum effect in the intertidal zone. They can dislodge the animals if not attached firmly to the substratum and throw them away or against rocks. Coral reefs are shaped and modified by wave action. Wave action also brings about mixing of oxygen and nutrients. Tides are caused by the gravitational pull of sun and moon on the waters of ocean. As earth rotates on its axis, there occur two high tides and two low tides each day; the average period between successive high tides is approximately 12 hours and 25 minutes. The lunar tides are almost double the size of solar tides and normally mask them except twice during the month i.e. on full moon and new moon days when earth, moon and sun are nearly in line and the gravitational pulls of the sun and moon are additive. This collective gravitational force causes the spring tides when high tides are very high and low tides are very low. When moon is an either quarter, the gravitational pulls of sun and moon interfere with each other, creating the neap tides of minimum difference between high and low tides. There are many factors which modify tides so that tidal patterns are neither entirely regular nor are thy same all over earth. The tidal range varies from less than 1 foot in the open sea to 50 feet in certain enclosed bays.

Currents – The sea is in continuous circulation and this is brought about by the currents. Air temperature difference between poles and equator set up strong winds, which together with rotation of earth create definite currents. In addition to wind-driven currents on the surface, deeper currents result from density differences created by variations in temperature and salinity. The equatorial currents and the winds also bring about the process of upwelling in certain regions of ocean. As the water is pushed towards equator by winds, it is deflected away from the coastal slopes. As the deflected surface water moves away, it is replaced by an upwelling of colder, deeper water that brings a supply of nutrients (which have been accumulated in the depths) into the sunlit portions of the sea. As a result regions of upwelling are highly productive. These regions of upwelling occur largely on the western coasts. Some of the important commercial fisheries such as tuna fishery off the California coast, the anchoveta fishery off Peru, and the sardine fishery off Portugal are supported by the upwellings. All these currents and upwellings prevent oxygen depletion in deep waters and make nutrients of deep waters available to producers of surface waters.

Estuaries

Estuaries are the areas where the freshwaters of streams and rivers meet the saltwater of ocean. It is a semi enclosed coastal body of water such as a river mouth or a coastal bay, which has a free connection with the open sea and which is strongly influenced by tidal action. The salinity of estuary is intermediate between that of seawater (salinity is about 35‰). and freshwater (salinity ranges from 0.065‰ to 0.3‰). Estuary is, thus, a transition zone or ecotone between freshwater and marine ecosystems. Estauaries differ in size, shape and volume of water flow, all influenced by the geology of the region in which they occur. They normally have a high silt content. As the river approaches the sea, the stream-carried sediments are dropped in the quiet water. They accumulate to form deltas in the upper reaches of the mouth and shorten the estuary. In some estuaries silt and mud accumulations become so high that they are exposed at low tides, thereby forming tidal flat, which divide and braid the original channel of estuary. On the seaward side of estuary, ocean currents and tides erode the coast line and deposit material, further shortening the mouth. If more material is deposited than is carried away barrier beaches and brackish lagoons appear.

Current & Salinity . Current and salinity are two important factors that influence life in the estuary. Estuarine currents are complex and highly variable in different estuaries and mainly result from the interaction of one-direction stream flow, which varies with season and rainfall, with oscillating ocean tides and with the wind. Salinity of estuaries varies vertically and horizontally and fluctuates between 0.5‰ to 35‰ Vertically the salinity may be the same from top to bottom when there are strong eddy currents to mix the water or the estuary may be completely stratified with a layer of fresh water on top and a layer of dense saline water on the bottom. At high tides a surface wedge of sea water moves upstream more rapidly than the bottom water. Being denser the surface seawater tends to sink and lighter fresh water rises and mixing takes place from surface to the bottom. This phenomenon is known as **tidal overmixing** which is aided by strong winds. But when the winds are still the river water flows seaward on a shallow surface over an upstream movement of seawater that only gradually mixes with salt water. Horizontally, the least saline waters are at the river entrance, and the most saline at the mouth of estuary. But in regions where evaporation from the estuary exceed the inflow of freshwater from river discharge and rainfall (during summer), a negative estuary develops in which horizontal stratification is reversed, with an increasing salinity towards the upper end of estuary. Salinity also varies with changes in the quantity of fresh water flowing in the estuary. Salinity is highest during summer and during periods of drought when less fresh water flows into the estuary and lowest during winter and spring when rivers and streams are discharging their peak loads. This change in salinity may happen rapidly and thus no stenohaline organism hope to survive in the estuaries.

Biota and adaptation to estuarine environment. Estuary, being a transitional zone between freshwater and sea derives its biota from the adjacent marine and riverine habitats as well as typical estuarine organisms. The major components are the species restricted to estuarine situations, such as oysters and crabs, and those that come from the sea, such as shrimps. Very few species are derived from freshwater and only those that are capable of osmoregulation in saltier water.

Producers of estuary are of three basic forms – phytoplankton, benthic microflora (algae living in and on mud, sand, rocks and bodies or shells of animals) and macroflora (large attached plants in the shallow regions of estuary, including sea weeds, submerged eel grasses and emergent marsh grasses). Sea grasses also support large populations of epiphytic algae.

Estuarine fauna includes zooplankton, dominated by copepods and other animals. Among the invertebrates are the sponges, coelenterates (e.g sea anemones) annelids (e.g polychaete worms such as *Nereis*, *Arenicola*, *Tubifex*) crustaceans (e.g *Balanus*, *Palaemon* and various species of crabs), amphipods, insect larvae and mollusks (e.g oysters, potamides). Vertebrate fauna is represented mainly by fishes such as mullets, mudpickerel, sea trout, flounders, catfishes, salmon, eel and angler fish and estuarine reptiles such as *Natrix*, *Crocodilus porosus*. Some fishes such as striped bass, shad and bluefish use estuaries as the feeding and nursery ground(place where young stages grow). Anadromous fishes such as salmon and eels depend on estuaries where they may reside for considerable lengths of time during their migration from salt to fresh water.

Organisms inhabiting the estuary are faced with two problems- maintenance of postion and adjustment to changing salinity. The majority of estuarine organisms are benthic and are securely attached to the bottom, are buried in the mud or occupy crevices and crannies about sessile organisms. The dominant benthic organisms are the oysters which may be attached to hard objects or may form reefs. Closely associated with oysters are encrusting organisms such as sponges, barnacles and bryozoans, which attach themselves to oyster shells. Beneath and between the oysters live polychaete worms, decapods, pelecypods and a host of other organisms. Burrowing forms are protected not only from the dislodging action of currents but also from dessication and changes in salinity. Organisms of estuary are essentially marine, able to withstand full sea water. Some cannot withstand low salinities and their populations decline along salinity gradient. Most estauaring organisms are euryhaline and can cope-up with changing salinities. However, a sudden influx of freshwater especially after heavy rainfalls, sharply lowers the salinity and causes heavy mortality of oysters and other sessile organisms. Fishes and other motile forms escape by simply moving out of the area.

Productivity. Estuaries are one of the highly productive ecosystems, second only to coral reefs and tropical rain forests. The main reasons for this high productivity are –

Estuaries have a diversity of producer organisms (phytoplankton, benthic microphytes and macorphytes) which are "programmed" for virtually year around photosynthesis.

An estuary is a "nutrient trap" that is partly physical and partly biological. Nutrients and oxygen are carried into the estuary by tides. If vertical mixing takes place, these nutrients are not soon swept back out to sea, but circulate up and down among organisms, water and bottom sediments (Figure 3.5). Organisms also aid in trapping and cycling of the nutrients. The retention and rapid recycling of nutrients by benthos, the recovery of nutrients from deep sediments by microbial activity and deeply penetrating plant roots or burrowing animals create a sort of self enriching system in the estuary.

The tidal action (back-and-forth movement of water) removes wastes and transport oxygen, food and nutrients so that organisms can maintain sessile existence.

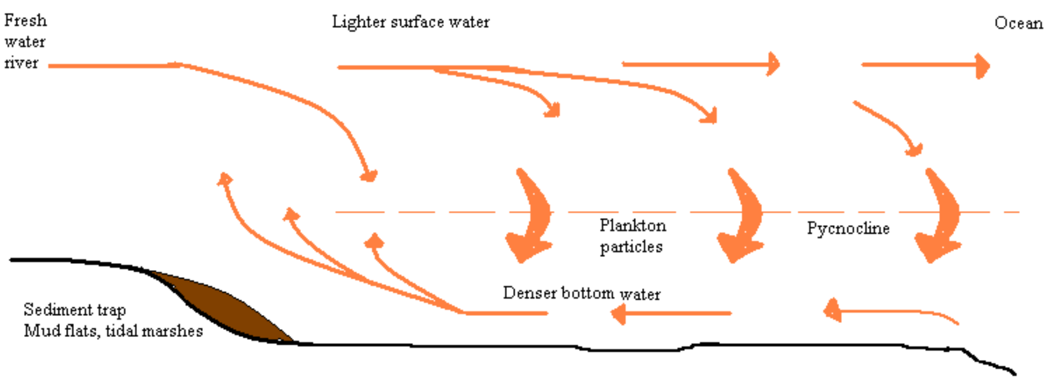


Figure 3.5 - Schematic diagram of circulation in a partially mixed estuary. Mixing of lighter freshwater with heavier sea water tends to produce a "nutrient trap" which retains and recirculates nutrients within the estauary.

Tidal marshes and Mangroves

Two very interesting and unique communities found in temperate and tropical coastal regions are the tidal marshes and mangrove swamps.

Tidal marshes are found on the alluvial plains about the estuary where tides and salinity play a significant role in determining the nature of community. The outermost tidal flats (towards sea side) are submerged twice a day in salt water and then exposed to full insolation of the sun; soil is poorly drained, poorly aerated and soil solution contains varying concentration of salts. Only plant species with wide range of salt tolerance can survive such conditions. The salt water cordgrass, Spartina is the dominant plant of tidal marshes. Different species of *Spartina* and other plants like glassworts (*Salicornia*), spike grass (*Distichlis)* and blackgrass (*Juncus)* form distinct zones from low marsh to high marsh. On the upland fringe of marsh grow shrubs like marsh elder (*Iva frutescens*), baybaerry(*Myrica)* and sea hollyhock (*Hibiscus palustris)*.

Two conspicuous physiographic features of the salt marshes are the creeks and the pond holes, called panes or salt pans. Creeks are the drainage channels that carry the tidal waters back out to the sea. These tidal creeks support a dense population of mud algae, diatoms and dinoflagellates and are photosynthetically active throughout the year. At high tides some of these are washed out and become part of estuarine plankton. Pannes are the circular or elliptical depressions which are flooded at high tides and remain filled with salt water at low tides. They support a distinct vegetation, which varies with the depth of the water and salt concentration. The dominant animals of tidal marshes are ribbed mussel (*Modiolus demissus),* fiddler crab (*Uca* spp.), marsh periwinkle (*Littorina* spp.), grasshoppers, grass shrimp sandhoppers (*Orchestia)* and seaside sparrow. On the high marsh the dominant animals are pulmonate snail (*Melampus),* meadow mouse (*Microtus)* and the seaside sharp tailed sparrow. At low tide the marsh is invaded by a host of predaceous animals like herons, egrets, gulles, terns, willets, ibis, raccoons. At high tides the fishes such as kill fish (*Fundulus),* silver sides (*Menidia)* and sticklebacks and blue crab which were restricted to channel waters at low tides, spread over the marsh. The tidal salt marsh is one of the most productive ecosystem because of tidal subsidy. Tides bring in new nutrients, sweeps out accumulated salts, metabolites and toxic wastes, and replaces anoxic interstitial water with oxygenated water.

Mangrove Swamps replace salt marshes as intertidal wetlands in tropical regions. They develop in those coastal regions where wave action is absent, sediments accumulate and mud is anoxic. The dominant plants are mangrove trees and other shrubs that can tolerate the salinity of sea water. Mangrove trees have shallow, widespreading roots and extensive prop roots (with pneumatophores in many species that bring in oxygen for the roots). These prop roots reduce tidal currents, cause extensive deposition of mud and silt and provide surfaces for attachment of marine organisms. A succession of mangrove species often forms pronounced zonation from open water to the upper intertidal region. In the Indo-Pacific region the seaward side is dominated by several species of black mangroves (*Avicennia)* and *Sonneratia.* Behind *Avicennia* is a zone of red mangrove, *Rhizophora* and beyond the level of high spring tides is a zone of *Bruguiera.* Attached to the stems and prop roots of these trees are the *Littorina* snails, oysters, barnacles and other marine animals. Burrowing into the mud are the fiddler crabs and the fish, mudskipper (*Periophthalmus).* The trees provide nesting sites for herons and other wetland birds; and alligators, crocodiles, bears, pumas and wild cats inhabit the forest interior. Productivity of southeast asian and central American mangrove forests equals that of tropical rain forests.

Sea shores

Sea shore is the place where sea meets the land. It is the littoral or intertidal zone roughly bounded by the extreme high tide mark (supra littoral fringe) and the extreme low tide mark (infra littoral fringe). The intertidal zone is the most variable zone in the entire sea, alternatingly exposed and submerged by the tides. Conditions, on seashores, thus change from hour to hour with the ebb and flow of the tides. At flood tide, the sea shore is a marine world; at ebb tide it is the terrestrial environment. Any organism that is to survive in the intertidal region must be resistant to exposure to air, periodic desiccation, extreme temperature fluctuations and intense solar radiations. Seashore inhabitants are essentially marine, adapted to withstand some degree of exposure to air for varying periods of time. Many plants of sea shore resist desiccation by containing jelly-like substances such as agar, which absorb large quantities of water and retain it while the tide is out; Many animals resort to burrowing or tubiculous mode of life to resist desiccation or suspend their activities during dry periods. Another outstanding characteristic of this region is the ever present action of the waves and seashore organisms have evolved different ways of resisting wave action. Many seaweeds have tough pliable bodies, able to bend with the waves without breaking, while the animals either are encased in hard calcareous shells, such as those of mollusks, bryozoa, starfish, barnacles and crabs, or are covered by a strong leathery skin that can bend without breaking, like that of sea anemone and octopus. Many sedentary shore animals (e.g. sponges, tunicates etc.) have special modes of adhesion which keep them firmly attached to the substratum. However, animals of sandy beaches escape wave action by burrowing into the sand. On the basis of nature of substratum seashores are of three major types – rocky, sandy and muddy.

Rockyshores

The rocky shores present solid substratum for growth of wide variety of algae and for attachment of many sessile animals. Sessile animals abound to the rocks are many sponges, colonial hydrozoans, anthozoans (e.g sea anemones) and bryozoans. The sedentary animals inhabiting the rocky shores are a variety of mollusks like limpets, mussels and oysters, barnacles and tunicates. Also abundant are the tubiculous polychaetes and boring lamellibranchs (e.g *Teredo & Pholas)* and others like crabs and octopus which live in the crevices of hard rocks. Echinoderms, specially sea urchins and star fishes are found here sometimes.

The most striking feature of rocky shore is the zonation of life which results from the varying conditions existing from one boundary (highest tide mark) of seashore to the other (lowest tide mark). All rocky shores have the following three basic zones, characterized by the dominant organisms occupying them (Figure 3.6).

Supralittoral fringe – At the uppermost end is a zone of bare rock marking the transition between land and sea. Next is the supralittoral fringe, where salt water comes only every fortnight on the spring tides. It is a black zone with patches of lichens and blue green algae on which the periwinkles (*Littoria)* graze. The rough and rock periwinkles found in this zone are the most resistant to desiccation of all the shore animals.

Littoral zone – It is the region covered and uncovered daily by tides and tends to be divided into subzones. In the upper reaches barnacles are most abundant whereas oysters and mussels are more abundant in the middle and lower portions of littoral zone and accordingly the subzones may be named as barnacle zone, oyster zone and mussel zone. Also common in the middle and lower portions are limpets and periwinkles. The dominant organisms in these subzones may vary from place to place as a result of local variations in substrate, wave action, light intensity, climate differences and also biotic interactions like grazing, interspecific competition and predation. The oyster zone has rich growth of green algae like *Enteromorpha* and *Ulva*. On the rocky shores of colder climates lower half of littoral zone has a dense growth of brown algae, commonly known as rockweeds (*Fucus* spp.). Blue mussels replace the rockweeds on the shores where hard surfaces have been covered in part by sand and mud. In the lower reaches of littoral zone the red alga, *Gigartina* may grow in association with mussels and together they form a tight mat over the rocks. The mussels act like hard substratum for sponges and tunicates. Besides mussels a variety of filter feeding bryozoans and brachiopods, tubiculous polychaetes (e.g *Serpula, Sabella, Terebela* etc.) and starfishes (Asterias, Astropecten etc.), sea urchins (Echinus, Echinocardium etc.) and brittle stars (Ophiothrix, Asteronyx etc.) inhabit this zone.

Infralittoral fringe – It is the zone uncovered only at the spring tides for short periods of time. This zone consists of forests of large brown alga, *Laminaria* (one of the kelps) with a rich undergrowth of other brown (*Fucus)* and red algae. Also present in this zone are sea anemones, starfishes and sea urchins.

Beyond the infralittoral fringe is the sublittoral zone, the open sea. On the rocky shores is present a distinct habitat of tide pools. These are the pools of water in rock crevices, in rocky basins, and in depressions left behind by ebbing tide. These tide pools are subject to wider fluctuations in temperature and salinity at low tide and suddenly return to sea conditions on the rising tide. Thus the organisms of tide pool must be able to withstand wide and rapid fluctuations in the environment.

The productivity of rocky shores is influenced by the wave action. Waves bring in steady supply of nutrients and carry away wastes. They keep the fronds of various seaweeds in constant motion, moving them in and out of shadow and sunlight, allowing for more even distribution of incident light and thus more efficient photosynthesis. By dislodging organisms from the rocks, waves open up space for colonization by algae and invertebrates and reduce strong interspecific competition.

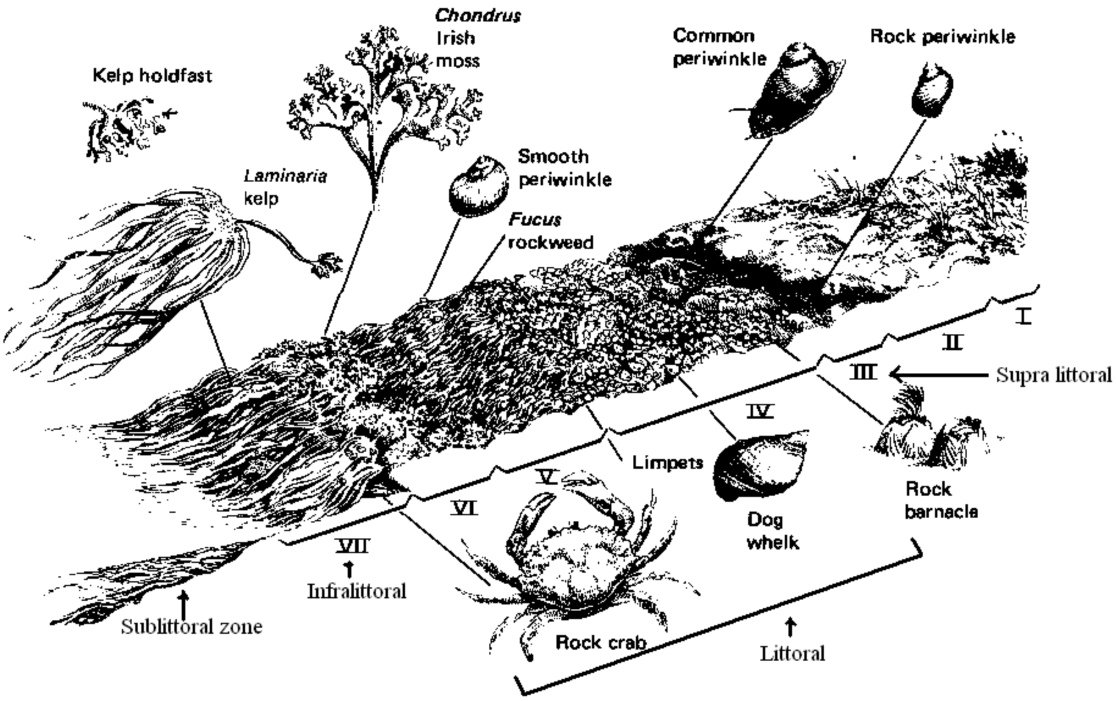


Figure 3.6 - Zonation on a rocky shore.

I – Land: lichens, herbs grasses

II – Bare rock

III – Zone of black algae and rock periwinkles

IV – Barnacle zone: Barnacles, dog whelks, common periwinkles, mussels.

V – Fucoid zone: *Fucus* and smooth periwinkles

VI – Chondrus zone: Irish moss

VII – Kelp zone: Laminaria.

(Source: Smith, 1990)

Sandy shores and Mudflats

In contrast to rocky shores which appear studded with life, both sandy shores and mudflats appear barren of life. They are also subjected to extremes of temperature, salinity, wave action etc. and in addition the constantly shifting substratum provides no surface for attachment of sea weeds and associated fauna. The latter makes life almost impossible on surface; life has retreated below the surface. The retention of water by the sand at low tide is one of the outstanding features of the sandy shores and make them suitable for animal life. Organisms living within the sand and mud also do not experience violent fluctuations in temperature and salinity because below a few inches both temperature and salinity remain almost constant throughout the year. Most animals of sandy and muddy beaches have adopted the burrowing mode of life. They belong to such diverse animal groups like nematodes, turbellarians, annelids, gastrotrichs, rotifers, mollusks, crustaceans, echinoderms, acrania and fishes.

Like rocky shores, sandy and muddy shores also exhibit zonation of life related to tidal influences (Figure 3.7)). These zones are: supralittoral zone (dominant organisms are ghost crabs and beachhoppers), littoral or intertidal zone (abundance burrowing animals of varied groups) and infralittoral zone (predominant organisms are starfishes, sand dollars, predatory crabs and fishes).

Sandy beaches and mud flats are essentially heterotrophic in nature, depending upon the imported organic matter as energy input. The detritus from seaweeds, dead animals, feces and materials blown in from shore accumulates within the sand and decomposed by bacteria. The products of decomposition are dissolved and washed into the sea by high tide. Bacteria on sandy and muddy beaches not only act as reducer organisms in energy flow but are the basic consumers of organic matter and are also the major source of food for higher level consumers. A number of deposit-feeding organisms ingest organic matter largely as a means of obtaining bacteria. Prominent deposit feeders are numerous nematodes, copepods, polychacte worm (*Nereis)*, gastropod (*Hydrobia)*, lugworm (*Arenicola)*, acorn worm (*Balanoglossus).* Some animals are filter feeders, obtaining their food from tidal waters. Associated with these herbivores are the predators, some of which are always present such as predatory crabs and gastropods, others like killfish and silversides come with incoming tides and still others like gulls and shorebirds hunt for food when the tide recedes. The primary productivity of sandy beaches is very low, the main producers being diatoms confined around the accumulated organic matter. However, on mudflats covered with algae, *Enteromorpha* and *Ulva*, the productivity can be substantial.

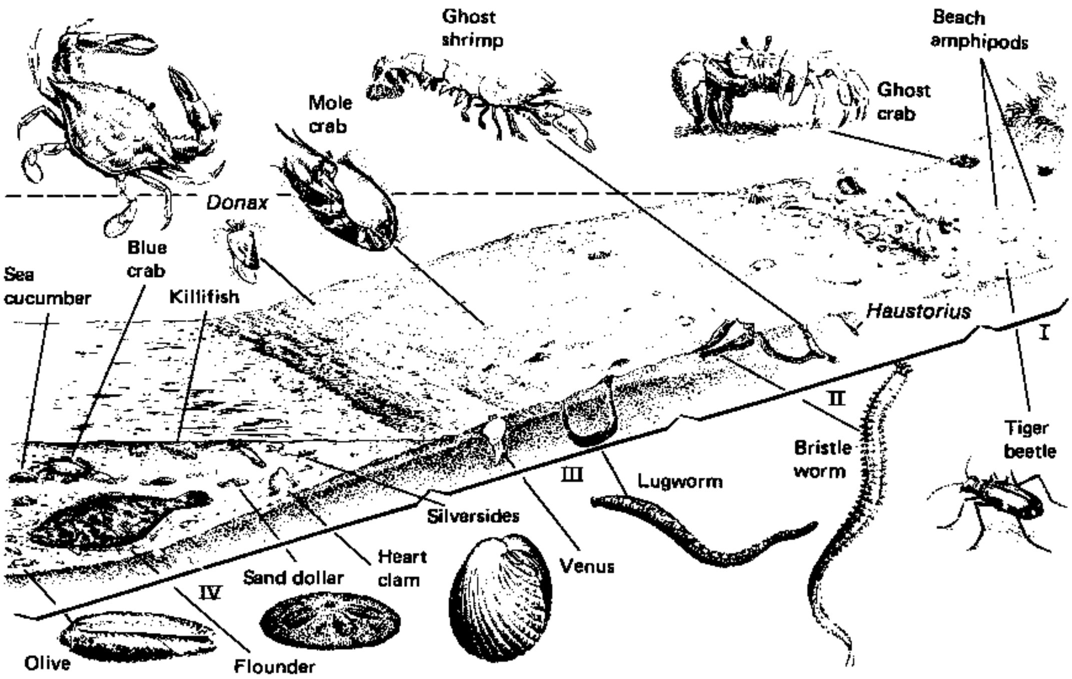


Figure 3.7 - Life on a sandy beach

I – Supratidal zone: ghost crabs and sand flees. II- Flat beach zone: ghost shrimp, bristle worms, clams III- Intratidal zone: clams, lugworms, mole crabs IV – Subtidal zone

The dashed line indicates high tide. (Source: Smith, 1990)

The Open Sea

Zonation . Beyond the rocky and sandy shores lies the open sea. Just like freshwater lakes and ponds sea also exhibits vertical and horizontal zonation(Figure 3.8). The two major regions of sea are **pelagic** or whole body of water lying above the ocean floor, and **benthic** or the entire sea bottom. The pelagic region is further divided into two zones: **neritic zone** which is the shallow water zone on continental shelf and **oceanic zone** which is the region of open ocean beyond the continental shelf. The **continental shelf** is the underwater extension of continent. The edge of continental shelf may be within a few kilometers of the shore, or it may be several hundred kilometers from the shore. On the basis of light penetration the pelagic region is broadly divided into two vertical zones – **euphotic zone** (photosynthetic zone) that extends from surface to about 200m in which there are seasonal fluctuations and sharp gradients in light, temperature and salinity and **aphotic zone** of very little or no light penetration. The aphotic zone of oceanic region is further divided into the following vertical zones. From 200m to 1000m is the **mesopelagic region** where very little light penetrates and where the temperature gradient is more even, gradual and without seasonal fluctuations. It has minimum concentration of oxygen but maximum concentration of nitrates and phosphates. Below mesopelagic is the **bathypelagic zone** lying between 700-1000m and 2000-4000m. The deep waters lying over the major plains of the ocean constitute the **abyssal pelagic** or **benthipelagic** zone that extends to about 6000m. Water of deep oceanic trenches is called **hadalpelagic**. The benthic zone (sea bottom) is also divided into three zones-the one underlying the neritic zone of continental shelf is called the **sublittoral** or **shelf zone**; the region of continental slope and rise is called ***bathyal zone*** that extend down to 4000m and contains trenches, canyons and ridges; and the bottom of broad flat ocean plains down to 6000m is called ***abyssal zone***. On the abyssal plains, there are extensive mountain ranges or midoceanic ridges, some of which have tips projecting above sea level. The bottom of deep oceanic trenches which drop down much below 6000m is called **hadal zone**.

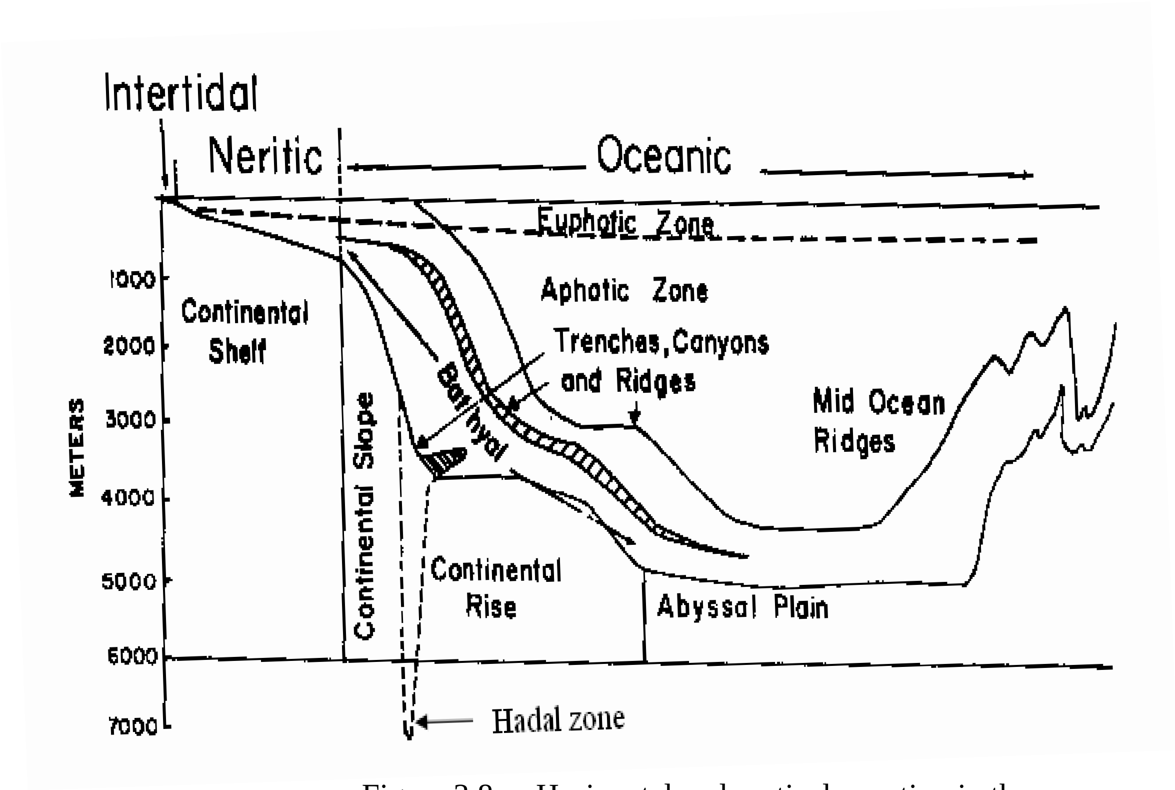


Figure 3.8 - Horizontal and vertical zonation in the sea

(Source: Odum, 1971)

Biota . The ocean has a rich diversity of species although their abundance is low. Every major group of algae and almost every major group of animals can be found some where in the ocean. The only striking omissions are the insects and vascular plants which have a few or no marine representatives. Light penetration, temperature, depth(pressure) and availability of food and nutrients are some of the factors which have a pronounced influence on the distribution of organisms in ocean.

Biota of Neritic region. The biota of neritic region is both richer and more diverse than that of oceanic region. The dominant producer organisms are diatoms and dinoflagellates. But in shallower regions(especially near the rocky sea shores) large, multicellular attached algae or "sea weeds" consisting of green, brown and red algae are of great importance and often form extensive forests or "kelp beds". The zooplanktons of this region are of two types- **holoplankton** (permanent plankton; those that remain planktonic throughout life) such as copepods, euphausids (commonly called krill), foraminiferans, radiolarians, tiny jelly fishes, ctenophores, free floating polychaete worms and arrowworms (chaetognaths) and **meroplankton** (temporary plankton; those that are planktonic for short periods in their life) such as pelagic larvae of fishes, ctenophores and of benthic organisms (such as crabs, marine worms and mollusks). The nektons of neritic sea comprise large crustaceans, turtles, sea snakes, squids, marine mammals (whales, seals, sea otters) and marine birds (e.g penguins) in addition to numerous species of fishes. The fishes include many species of sharks, herring like fishes (such as menhaden, herring, sardine and anchovy), cods and their relatives (such as haddock and Pollack), salman, trout, flat fishes (flounder, sole, halibut) and mackerels (tuna & bonito).

Biota of Oceanic region . The oceanic region is less rich in species and numbers than the coastal areas. Some oceanic species are also common in neritic region but many seem to be restricted to the oceanic region. Oceanic phytoplanktons are predominantly micro and nanoplankton and mainly diatoms and dinoflagellates. The zooplanktons of this region are mostly holoplankton-the same groups as described in neritic region but smaller forms. Most species of zooplankton undertake diurnal vertical migrations to escape from the high light intensity during day time and then move up to feed on phytoplanktons at night. Planktons are at the mercy of currents and their composition and distribution varies from place to place, season to season and year to year. But nektons, the large swimming animals can move at will in the water column. They range in size from small fish to large squids, nautili, sharks, whales, seals and marine birds. Air breathing vertebrates like turtles and whales are found mainly in the photic zone, but fishes extend from sea surface to the bottom. Some fishes such as herring, tuna, shark, sardine, mackerel and anchovy are more or less restricted to photic zone. Others are found in deeper mesopelagic, bathypelagic and abyssal pelagic zones or can move between them and the surface, as the sperm whale does.

All pelagic organisms have evolved adaptive devices to remain floating and swim actively. To resist sinking they have lighter bodies by having weakly calcified or uncalcified shells e.g. in pelagic gastropods and lamellibranhs or reduced exoskeleton e.g. internal, uncalcified shell of *Loligo* or weak skeleton in fishes. To reduce specific gravity some animals incorporate large amounts of water in their tissues e.g *Cyanaea* (a jelly fish), *Salpa* and *Pyrosoma*; others like diatoms have oil droplets in their cells; and fishes like cods and many selachians store large amounts of fat as storage tissue. Certain coelentrates like *Physalia* and *Velella* have gas filled pneumatophore or float. Bony fishes possess air bladder that perform hydrostatic function. Active swimming in animals is accomplished by having cilia in small animals like protozoa, small metazoa, many larval stages and ctenophores; by having oar-shaped limbs e.g parapodia of annelids, modified antennae in copepods and wing like foot in pteropods; by having stream lined body e.g in many fishes; by having undulating movements of lateral fins as in rays, sharks and cephalopods or of whole body as in fishes, whales and seals.

The density of life tends to decrease with increasing depth. The main reason is that the aphotic zone of ocean depends upon the organic matter falling from the upper thin euphotic zone as energy source and such food is limited. Most organic matter is consumed, decayed or dissolved before it reaches the deepest water or the bottom. The other sources of food in deep sea include saprophytic plankton which exist in darker regions, particulate organic matter found from dissolved organic matter and wastes from coastal areas and large dead animals. Residents of deep sea have special adaptations for securing food. Some have enormous mouth and expandable abdomens to swallow prey larger than themselves, others resort to mimicry or use bioluminescence to lure prey. Bioluminescence is common among fishes, crustaceans (euphausids), cephalopods (squids), many coelenterates, few annelids and some starfishes. Bioluminiscance has reached its greatest development in bathypelagic and benthipelagic regions. The deep sea presents uniform environment that do not change for hundreds of years together. But the conditions for existence are harsh with low temperature, immense pressure, scarcity of food, perpetual darkness and absence of currents, so that interspecific struggle is minimum. As a result archaic forms have been able to maintain themselves almost unchanged. Ancient forms like *Limulus, Lingula, Amphioxus, Spirula* and *Nautilus* are now confined to deep sea, although their relatives have long been extinct in other areas of world.

Benthic fauna – The organisms inhabiting the benthic zone are of two types-Organisms living on the surface, either attached or moving freely on the surface are referred as ***epifauna*** (e.g sea lilies, sea fans, sea anemones, sea cucumber, sea urchin, sponges, certain crustaceans and benthic fishes) and the organisms that dig into the substrate or construct tubes or burrows are referred as **infauna**(e.g polychaete worms, turbellarians, nematodes, rotifers, clams and crabs). There is gradual transition of benthic life from the rocky and sandy shores to the abyssal depths of ocean. Organisms colonizing the bottom are influenced by nature of the substrate. If the bottom is rocky epifauna predominates, and where the bottom is covered with sediments infauna is more common. Large areas of the bottom of the ocean are covered with finely divided sediments, commonly called "oozes", consisting largely of skeletal remains of planktonic organisms(e.g. calcareous and siliceous shells of foraminiferans, radiolarians and diatoms). Below 4000m hydrostatic pressure causes some form of calcium carbonate to dissolve. Hence, at 6000m and lower sediments consist largely of red clay, rich in aluminium oxide and silica. Within the sediments there are three vertical layers that are often distinguishable by colour and that relate to oxidation-reduction reactions. The surface or oxidized layer is yellowish in colour and is relatively rich in oxygen, ferric oxides, nitrates and nitrites. It supports bulk of benthic animals and a rich growth of aerobic bacteria. Below the oxidized layer is a grayish transition zone which is the home of chemosynthetic bacteria and nematodes. The third layer is the black reduced layer, characterized by a lack of oxygen, iron in the ferrous state, nitrogen in the form of ammonia and hydrogen sulfide. It is inhabited by anaerobic bacteria, such as sulfate reducers and methane bacteria.

The community of deep benthic regions is strictly heterotrophic depending entirely for its source of energy on the organic matter finally reaching the bottom. Bottom organisms have adopted different feeding strategies-some may be filter feeders obtaining suspended organic particles from the water; or deposit feeders, getting food particles from sediments; or they may be predators. Bacteria are abundant in upper layers of sediment where large quantities of organic matter are present and are an important source of food for deposit feeders.

On the abyssal zone of ocean floor, there are volcanic ridges with **hydrothermal vents** (high temperature deep sea springs) that emit jets of hot water (about 300°C-450°C) rich in hydrogen sulfide and other minerals like zinc, copper and iron that heat the surrounding water to 8° –16° C, considerably higher than the 2° C ambient water. Associated with these vents are chemosynthetic bacteria that oxidize the reduced sulfur compounds, such as hydrogen sulfide, to release energy, which they use to form organic matters from carbon dioxide. These bacteria are the primary producers of this region and are consumed by other inhabitants such as giant clams (e.g *Calyptogena magnifica*), mussels, polychaete worms, crabs and vestimentifera worms (e.g *Riftia pachyptila*).

Productivity .The open sea constitutes about 90 percent of the total ocean surface, yet its primary productivity is considerably less. The basic reason for low productivity is the very small autotrophic zone (only upto 100m deep) that can support plant life which is largely phytoplankton. The density of phytoplankton is low and their distribution patchy because most of the open sea is nutrient poor. The dead organisms sink below the lighted zone into the dark benthic water, depriving the upper layers of nutrients. The depletion of nutrients is most pronounced in tropical waters where a permanent thermal stratification prevents an exchange of nutrients between the surface and the deep waters. The temperate oceans are more productive, largely because a permanent thermocline does not exist and like termperate lates experience nutrient overturn during spring and fall. Most productive are coastal waters and regions of upwelling.

Coral reefs

Coral reefs are one of the most beautiful and specialized ecosystems, widely distributed in warm shallow waters of tropical and subtropical seas. They are built by carbonate-secreting organisms of which corals(coelentrata, Anthozoa) are the most conspicuous (hence the name coral reef) although other organisms like coralline red algae (Rhodaphyta, corallinaceae), foraminifera and mollusks also contribute equally to their structure. Coral reefs are built only under water at shallow depths and need a stable foundation upon which to grow. Such a foundation is provided by shallow continental shelves. Reef building corals grow best at waters having average annual temperature of 24^0 C, a depth of 40-50 metres and average salinity of 35‰. Reefs are built upto the sea level.

Coral reefs are of three types:

- **Fringing reefs** that grow along the rocky shores of islands and continents.
- **Barrier reefs** parallel shores lines along continents.
- **Atolls** are coral islands that begin as horseshoe shaped reefs surrounding a lagoon.

Coral reefs are complex ecosystems involving a close relationship between coral and algae. One kind of algae, the so called zooxanthellae (a symbiotic endozoic dinoflagellate algae) live in the tissues of coral polyp while other kinds of red and green coralline algae and filamentous algae live in the skeleton around or below the animal bodies. Still other species of algae are found everywhere over the limestone substrate. All these algae are chief producers in coral reef ecosystem. At day time, the zooxanthellae inhabiting the corals carry on photosynthesis and directly transfer organic material to coral tissue. At night coral polyps feed on zooplankton, securing phosphates, nitrates and other nutrients needed by them and their symbiotic algae. The nutrients are, thus, recycled between the anthozoans and the algae. Besides zooxanthellae all other types of algae, sea grass, sponges, phytoplankton and a large population of bacteria also contribute to the productivity and recycling of nutrients. Coral reefs are among the most highly productive ecosystems of the world; net productivity ranges from 1500 to 5000 gm C/m^2 /yr. In addition to abundance of light and oxygen the two major factors responsible for high productivity are –(1) Efficient biological recycling of nutrients by coralline community retain nutrients within the system and (2) Coral act as trap for nutrients that come with the flowing water.

This high productivity and diversity of habitats within the reef supports high diversity of life that is equaled only by tropical rain forests. An immense variety of micro-organisms, mollusks, echinoderms, crustaceans, polychaete worms, sponges and fishes live in the coral reefs. Probably 30 to 40 percent of all fish species on earth are found on coral reefs. Prominent herbivores include snails, sea urchins and herbivorous fishes that graze on algae and which in turn are consumed by octopuses, sea stars and carnivorous fishes.

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